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SNOW STUDIES

ON THE JUNEAU ICE FIELD

By

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Broadway at 156th Street
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NOTE:

Pertinent to the series of JIRP Reports, Report No. 7 which constitutes the work of the 1950 summer expedition and Report No. 10, relating the 1951 summer studies, are being prepared for publication.

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INTRODUCTION

The following report discusses the planning, execution and results of a program of snow studies carried out on the Juneau Ice Field during the summer of 1952. The work was an integrated part of the long-range glacier study program of the Juneau Ice Field Research Project, operating on the ice field for the fifth consecutive year under the auspices of the American Geographical Society and with the financial support of the Office of Naval Research, Task Order N9onr-83001. Observations were begun on the 27th of May, and terminated on the 23rd of August, encompassing the beginning and major part of the 1952 ablation season. Work was centered at Camp 10, the Project base camp, with outlying sites, both up- and down-glacier, being visited periodically by means of an oversnow vehicle.

Plans for snow investigations on the Juneau Ice Field originated late in the spring of 1952. Earlier planning had been directed toward a somewhat similar program for execution on the Greenland Ice Cap in 1952 as a part of a research project to be carried out there by the American Geographical Society. When it was learned that logistical difficulties would force the postponement of the Greenland expedition, the possibility of diverting the momentum already gathered toward a summer of work on the Juneau Ice Field was immediately considered. Plans for the Juneau field party, already under way, fortunately permitted expansion to include a program of snow observations which promised to contribute, at least in minor measure, to the store of information being accumulated about glaciological conditions prevailing in the Juneau Ice Field region.

When reconsidered in the light of possible operation on the ice field, the snow program offered the prospect of being executed with a two-fold purpose. First, as mentioned above, it would constitute a contribution to knowledge of ice field snow conditions; and second, it could evaluate the usefulness and practicality of various snow test instruments, with special reference to future work in Greenland. The extent to which these objectives were fulfilled during the 1952 season is dealt with on the following pages.

The snow test equipment is discussed at the beginning and includes standard and newly designed instruments, both used for the first time on the ice field, as well as items used during previous seasons. Suggestions have been made for the improvement of instrument design wherever desirable, but it must be borne in mind that these suggestions follow from a single season of testing under a limited number of snow conditions, and may not necessarily represent the best possible means of improvement.

The research program is presented subsequently and is limited to a description of methods used in the snow studies, notes on observations, data, summarized principally in graphic form, and an outline of the more salient conclusions to be drawn therefrom. In general the work discussed is that of observation and recording of data. A thorough analysis and deduction of all the significant conclusions from the acquired data are felt by this writer to lie beyond the scope of his abilities, and must be a matter for consideration by a more mature and experienced scientist. An attempt is made to summarize the more obvious conclusions, but these should not be considered to constitute a complete analysis.

SNOW TEST EQUIPMENT

Ablation Stakes

Throughout the summer field season, ablation measurements of the 1952 snow cover were maintained at a number of different points on the Juneau Ice Field. These measurements were made by means of ablation stakes, driven into the snow to serve as reference points from which to measure changes in surface level. At the beginning of the season, this observer, being a newcomer to the study of glaciology, followed the precedent established during the previous seasons of the Project, and used as ablation stakes lengths of 1 x 2 inch (in.) and 2 x 2 in. lumber, painted white. Marks were made at the upper ends of these stakes, and distance from these marks to the snow surface was measured periodically to ascertain ablation. Since no definite information was available about the depths to which these stakes had been implanted during previous work, a series of tests was made to determine the effects, if any, of implanting ablation stakes at different depths. Four different stakes were implanted to depths of 30, 60, 90, and 120 centimeters (cm.), and were separated from one another laterally by intervals of approximately two meters (m.). The two shorter stakes were one-inch wooden dowels, painted white, while the two longer ones consisted of 1 x 2 in. lumber, also painted white. Lengths were so chosen that all the stakes protruded about the same distance out of the snow. Longer stakes were not available at this time, so tests at greater depths could not be made. The two longer stakes recorded slightly greater cumulative ablation than did the shorter, but the difference was small, and probably falls near the limit of measurement error. It was necessary to reset the two shorter stakes every two or three days to keep them from melting out and tipping over. Differential ablation caused rapid formation around each stake of conical cavities which soon reached diameters of 20-25 cm. and made accurate measurement of the snow level on the stake quite difficult. This formation of cavities, or craters, around the stakes was soon observed to be a major obstacle to accurate ablation measurements, especially when it was foreseen that stakes at outlying observation sites could be reset only every two weeks or so, while stakes reset even every 24 hours developed appreciable craters on days of high ablation (See Fig. 1).

During this early-season (late May to mid-June) period, a small party was in the field, and the only camp occupied was the main base, Camp 10 (for location, see Fig. 12). The ablation records mentioned above were obtained at Camp 10A, located at the foot of the nunatak upon which the base camp facilities were constructed. Shortly after observations commenced, a single ablation stake was set up at Camp 10B, located opposite the base camp and a mile out on the Taku Glacier, and irregular records maintained for a period of about one month. By accident, the material chosen for this stake was 3/8 in. thin-wall, steel tubing, painted a dark olive green (sectional radio antenna). This was implanted to a depth of approximately 2.5 m., and was not reset during the entire period of observation. After some two weeks of observation, it was noted that the ablation crater around this steel tube was only five cm. in diameter. This led to the suspicion that white-painted wooden stakes might not be the most suitable medium for ablation measurements. Accordingly, a series of tests was made with such materials as were available in the field to ascertain what type of stake would create the smallest ablation crater and consequently permit the longest period of accurate observation without resetting. Materials tested were wood, steel tubing, aluminum tubing, aluminum strips, and steel strips, all in as large a variety of diameters as could be obtained. Types of surface included white paint, dark paint, unpolished aluminum, polished aluminum, polished steel, and natural wood. All surfaces and sizes were not available in all the materials, which themselves were limited in variety, so that the tests could not be considered in any way comprehensive, although one outstanding fact soon emerged. The size of the ablation crater around a given stake appeared to bear very little relation to the material, color, or reflectivity of the stake, but was almost entirely a function of stake diameter. Since the tests were admittedly limited in scope, and the use of ablation stakes painted white seems to be a custom honored by usage, this conclusion is advanced with some hesitation. Plans for ablation measurements during the balance of the season were, nevertheless, based on the results of these tests. The stake adopted consisted of three unpainted wooden dowels 3/16 in. in diameter, spliced together end-to-end to form a total length of approximately three meters. In use, this stake was implanted to a depth of about 2.5 meters. Since the thin wooden dowels were not strong enough to be driven directly into the hard snow, a hole was first made with the 3/8 in. steel tube and the ablation stake inserted in this. The appearance of one of these stakes two weeks after being implanted is shown in Fig. 2. Note the contrast with Fig. 1.

Some tests were made later in the summer, when short intervals of time spent at the base camp permitted occasional experiments, to see if further improvement of ablation measuring methods could be discovered. One method evolved appeared to enable ablation to be read to about the nearest 1.0 millimeter (mm.) without any complex equipment, although it was somewhat limited in application. This method followed from the reasoning that if a small ablation stake were better than a large one, then the best would be no stake at all. A small hole was carefully punched in the snow with the 3/8 in. steel tube, care being taken to have the hole terminate on the upper surface of a heavy ice band which had been located by previous probing. The depth of the hole would, of course, vary with the depth at which an ice band could be located. In the case of the experiment here described, it was about 0.8 m. below the snow surface. A short wooden plug, formed of a 3-cm. length of 3/16 in. dowel, was then inserted in the hole and pushed down to rest on the ice-band. The top surface of this plug then served as a reference point from which the distance to the snow surface was measured at intervals to determine ablation. Since the short plug rested on an iceband at some distance below the surface, it was presumed to have undergone no appreciable movement in respect to the snow around it. Measurement to the surface was made by first inserting a pointed length of dowel into the hole until it rested on the plug, and then carefully marking the snow surface level on this dowel with a pencil. It was necessary to use a tapering point on the dowel, since if the lower end were square, it would carry down a small quantity of snow on insertion, forming an obstruction between the dowel and the plug. As the dowel was in the hole each time for only the few seconds necessary to make a measurement, no opportunity occurred for an ablation crater to form, and a clean, square lip from which accurate measurement could be made always remained at the edge of the hole. The small hole suffered no appreciable alteration, as had been anticipated. The major limitation of this method is that it is restricted to periods of ablation only, since any snow accumulation would obscure the small hole and make readings difficult, if not impossible, to obtain.

A reference point suspended above the snow between two stakes a short distance apart may also be used to obtain ablation readings on undisturbed snow. Sharp (1951a) has described an ablatometer of this type which offers means of precision measurement. The method of measuring up to the snow surface from the bottom of a hole, as here described, instead of down from a reference point above the surface, appears to have been anticipated a half-century ago by Hamberg (1904).

Density Corer

Snow density measurements were made by collecting and weighing samples of known volume. The coring device used to collect these samples, a steel tube of a design used on previous seasons of the Project, is pictured in Fig. 3. This coring tube is equipped with a toothed edge for ease of insertion in hard snow, and the edges of these cutting teeth are beveled inward, so that a snow sample is collected with a diameter equal to the outside diameter of the tube. In collecting a sample, the tube is driven into the pit wall until the snow surface is even with a line scribed on the tube near its rear end. The tube is then carefully withdrawn with its enclosed snow sample, a metal gate inserted in a slot 4 cm. back from the cutting edge, and the snow between this plate and the cutting edge of the corer is removed. The remaining snow in the corer then supposedly corresponds to snow which originally occupied a volume of 600 cubic centimeters (cc.) in its undisturbed state. For the particular coring tube used, careful measurement showed this volume to be 616 cc. This error of 16 cc. is a fixed one for which a correction may be made when computing density values, but unfortunately a further error for which correction cannot be conveniently made arises from the design of this coring tube.

The second source of error is introduced by the inward bevel of the cutting edge. The consequence is the cross-sectional area of the snow sample being reduced from its original value corresponding to the outside diameter of the coring tube, to a value corresponding to the inside diameter. The end result is a reduction in volume of the snow sample by compression, the amount of reduction being a function of the snow type and its consequent compressibility. This in itself would not be objectionable, but when a constant volume of snow is removed from the 4 cm. space between the slot and the toothed end, the collected volume of snow then becomes a function of snow compressibility. For soft snow types, compressibility is high and the sample is simply reduced in cross-section without extrusion, accompanied by maximum reduction in volume.

The end of the snow sample within the coring tube then has the same position in respect to the tube as the snow surface outside, that is, it is even with the line marked on the outside of the tube. When a hard type of snow, with low compressibility, is encountered, then volume reduction is at a minimum and extrusion predominates, resulting in a collected snow sample longer by some length, x, than the distance the tube was inserted into the snow (See Fig. 6). Observations showed that x varied from zero to approximately five cm. for the various snow types encountered during the summer work, resulting in an error in collected volume up to one part in 100. Sharp (1951b) has used a density corer of this same design, and does not consider this error large enough to be significant, which it is not in soft snow. The magnitude of the error increases, however, with snow hardness, and in very hard snow becomes appreciable.

It is recommended that corers of this design be replaced by the standard 500 cc. coring tube for future density work on the Project. This standard tube has long been in use in Switzerland, and has also been adopted for snow density work by the Snow, Ice and Permafrost Research Establishment, U. S. Corps of Engineers. This is a simple tube, inside diameter 58 mm., length 190 mm., wall 1 mm., with an outward bevel on the cutting edge, which reduces snow compression to a minimum. Much greater accurary in collected volume of snow can be achieved because this tube is not withdrawn from the snow with the collected sample, but rather is inserted beyond its length in the pit wall, and then is carefully dug out with a sharp-edged metal plate and the ends smoothed off square while it is still in place in the snow. By using a number of tubes, the density samples from an entire profile may be collected at once and the work of density determination greatly accelerated. The Swiss report density values to three significant figures using this method.

Cone Hardness Gauge

During the pit studies of the 1952 snow cover, snow hardness was determined with the cone hardness gauge (Kegelhärteprüfer), recently perfected at the Swiss Federal Institute for Snow and Avalanche Research at Davos. This gauge consists of a spring-driven shaft, tipped with a conical point, whose penetration into the snow when released by a trigger serves as a basis for computing snow hardness. The spring tension is adjustable to permit use in a wide range of snow types (See Fig. 4). The method of computing the snow hardness, expressed in kilograms, has been described by de Quervain (1950). The formula given in this reference for computing the hardness is:

$$R_k = \frac{E - (x + x_o)}{x - 0.57}$$

Where R_k = cone hardness in kilograms (kg.)

x = penetration of the point into the snow (cm.)

x_o = distance traveled by point before striking snow (cm.)

E = spring energy (kg-cm.)

De Quervain (1953) has subsequently pointed out that an error occurred in the printing of the formula, and that it should read:

$$R_k = \frac{E - \rho(x + x_o)}{x - 0.57}$$

Where ρ = friction of shaft in its guides (kg.)

= approx. 0.02 kg.

Because of its light weight and compactness, especially when compared with the ram penetrometer, the cone hardness gauge is a very useful instrument in the field. It does, however, require excavation of a pit to give direct access to each layer of snow being examined.

Rather more care is required on the part of the operator to give consistent results than in the case of the ram penetrometer, and even then a scattering of values is observed when the gauge is used to test very hard or very soft snow. When testing hard snow, recoil of the instrument frame must be guarded against since, if the frame of the gauge is not held firmly against the snow, sufficient recoil occurs to affect appreciably the measured value of cone hardness. The scattering noted when measuring very hard snow, at least in the case of hard summer snow in an advanced state of firnification, is probably because the diameter of individual crystalline aggregates in the snow approaches the same order of magnitude as the diameter of the conical point, which then no longer finds a uniform and homogeneous resistance to penetration. It was also noted that repeated use on very hard snow caused the arrow shaft to become slightly bent, materially increasing the sliding friction in the guides.

With very soft, new-fallen snow, where low spring tension settings (scale 0.1-0.2) are required, the loss of energy by the sliding arrow to the snow often becomes smaller than the loss to friction in the guides, and hardness values must be regarded with suspicion.

Plastic Replica Techniques

Attempts to obtain plastic replicas of snow samples were made along the lines established by Schaefer (1948), with the object of ascertaining whether such techniques would be applicable in the field for obtaining permanent records of snow grain size and type from pit walls. Preoccupation with other phases of the work restricted to a great extent the time which could be devoted to this problem, but it was soon confirmed that the technique was limited by the high air temperatures and rapid melting encountered during summer days on the ice field. It was found possible to prepare replicas of small (2-4 sq. cm.) areas of snow surface, in locations sheltered from direct solar radiation, by mixing table salt with the surrounding snow and freezing the surface for a period long enough to permit evaporation of the plastic solvent.

The medium used was a five per cent solution of "Formvar 15-95" in ethylene dichloride. The replicas were prepared on the surface of a thin polyethylene film stretched over a small frame.

This method, at least in the limited way in which it was tried, does not appear entirely satisfactory for recording the snow grain characteristics of coarse-grained old snow, as the area of contact of the large, rounded, snow grains and aggregates with the flat plastic film is small, and the resulting replica pattern gives little evidence of snow grain size and shape.

The possibilities of plastic replica technique as a quick and convenient means of securing snow data from pit walls for later leisurely study warrants further investigation, but the present method needs to be modified for use on the Juneau Ice Field during summer because of prevailing temperatures above the freezing point of water.

Ram Penetrometers

Part of the regular program of pit profile study involved the determination of snow ram resistance. The snow investigator is indebted to Haefeli (1939) for the introduction of the ram penetrometer as an instrument permitting the measurement of hardness variations with depth in a snow cover without the necessity of digging a pit. The ram resistance, expressed in kilograms, is determined by observing the penetration of a conically-pointed tube under the repeated impact of a falling weight, and substituting the figures thus obtained in the following formula:

$$R_r = \frac{X \cdot (R \cdot h)}{\Delta} + (R + Q)$$

R_r = ram resistance (kg.)

R = weight of ram-weight

h = fall distance of ram-weight

Δ = penetration of point into snow for x falls of ram-weight (cm.)

Q = weight of penetrometer tube (kg.)

X = number of blows from weight between two successive penetration readings

When the standard ram penetrometer, intended for use on the Project during the 1952 season, failed to arrive because of shipping difficulties, it became necessary to improvise a penetrometer from materials at hand. The only suitable material for improvisation which could be located on the ice field was one of the sectional whip antennas supplied with the U. S. Army RT-77/GRC-9 radio set (See Fig. 5). This antenna consisted of 3/8 in. thin-wall, copper-clad, steel tubing in three foot threaded sections, and fortunately proved to be made of an extremely strong, high-tempered steel. A heavy steel bolt, plus three nuts, was forced into the end of one of the sections and filed by hand to an approximate 60° cone to form the point. The point diameter was 1.1 cm., slightly larger than the steel tube. The ram weight was made by fitting a small funnel around a short section of steel tube and pouring it full of Babbit metal to form a total weight of about 0.3 k_g. A 3/16 in. hardwood dowel served as a guide rod for the falling weight. Each section of tubing was marked at 2-cm. intervals with a file, and each section weighed 0.15 k_g. ("Q" in the ram formula).

Operation of this improvised penetrometer was, on the whole, quite satisfactory, with an advantage actually being gained by the use in hard snow of a smaller-diameter point than the 4-cm. one of the standard penetrometer. A heavier ram weight, say 0.75 k_g. would have been preferred to the 0.3 k_g. one, which made operation slow in very hard snow. The use of a lighter ram weight does, however, have the advantage of increasing sensitivity to such structures as thin icebands which might otherwise be missed.

Up to five sections were used, yielding ram profiles to a depth of 4.7 meters. At such depth there is a slight increase in observed values of ram resistance due to friction between the long tube and the snow. The magnitude of this error was not measured, but is estimated to be quite small in comparison with the high values of ram resistance obtained at the depths where it would be greatest.

A further advantage of the small-diameter penetrometer was that it could be readily driven by hand through the 1952 snow cover under all conditions encountered on the ice field. With its inscribed centimeter scale, it thus provided a quick and convenient means of measuring accumulation wherever the underlying firn surface had a high enough ram resistance to be detected by hand.

Delivery late in the season of a standard penetrometer loaned by the U. S. Army Corps of Engineers' Snow, Ice and Permafrost Research Establishment (SIPRE), permitted comparison with the improvised penetrometer for purposes of calibrating the latter. Ram profiles were made side-by-side with the two instruments under as many different snow conditions as were feasible, and an average ram resistance ratio (standard instrument to improvised) of 6.12:1 was established. The theoretical ratio, based on comparison of cross-sectional areas of the points, would be 13.2:1. The necessity for actual calibration tests in such a situation has been demonstrated by experiments previously made by this writer, which showed that the measured ram resistance of a given snow layer is not a linear function of point cross-section, and is also dependent on the size of the ram weight.

On the basis of experience gained this summer, the construction and use of a regular ram penetrometer with a smaller point, say diameter of two cm., are recommended for work in hard summer snow and firn.

Snow Camera

Objective classification and recording of snow grain type is a problem which has long confronted snow investigators. Even with the most elaborate system of classification, the personal factor introduced by the observers often makes accurate comparison difficult. Further difficulties are introduced by the fact that more than one system of snow classification is presently in use.

When plans were first being directed toward a program of work in Greenland for the summer of 1952, the suggestion was made by Dr. Henri Bader, of SIPRE, that photomicrography of snow grain size and type be adopted as a standard means of recording these characteristics. The loan of a low-power binocular microscope, to be used in conjunction with a standard photomicrographic attachment, was offered by SIPRE for use in Greenland for this purpose. When changes in plans shifted the summer snow study program to Alaska, this instrument was no longer available, and it became necessary to provide a substitute. Since the field use of standard photomicrographic equipment for snow studies entails a number of disadvantages, such as high cost, weight, time of setting up and operation, and the necessity for a strong light source, this appeared to be a good opportunity to experiment with photographic equipment, keeping these problems especially in mind. Accordingly, an experimental model of a snow camera was constructed late in the spring of 1952 and used with moderate success during the summer field season in Alaska.

The general appearance of this camera is illustrated in Figs. 7 and 8. While the material for this test model was selected for low cost and ease of adaptation, and the assembly was accomplished with only a few simple tools, except for the machining of the lens barrel extension, considerable effort was devoted to designing an instrument that would be convenient and practical for field use. The first step was to eliminate the weight and bulk of the microscope by substituting for it a camera lens of sufficiently short focal length to permit close-up focusing on snow grains while still keeping the overall camera dimensions as small as possible. Further compactness was made possible by the introduction of a right-angle prism in front of the lens, thus permitting the optical axis of the camera to be turned parallel to the object plane. The need for compactness and low operating cost dictated the selection of a 35 mm. camera, which also conveniently provided in the same unit the required short focal length lens, in this case, one of 5 cm. Portability obviously required a battery-operated light source, but to keep the weight down by using small flashlight batteries, the light source was necessarily limited to one of low intensity. To supply sufficient illumination of the object plane which would keep the exposure within reasonable limits, it was necessary to place the two-cell flashlight bulb within about two cm. of the center of the object plane. The small amount of heat radiated by this bulb does not appear to affect appreciably the snow sample during the short interval of exposure. The focus of the camera is fixed, and is adjusted to provide a 1:1 image-to-object ratio, thus permitting reproduction of the snow grains in their natural size by making contact prints from the negative. A larger scale may be achieved by enlarging from the negative.

When the camera is used in the field, a snow sample is collected and placed within a circle inscribed on a flat plexiglass plate to correspond to the object field of the camera. This plexiglass plate, also illustrated in the accompanying figures, has been buffed with a fine abrasive to eliminate specular reflection. The camera is then placed over, and in alignment with, the plexiglass plate, and the exposure made. With a lens aperture of f:9 to give a reasonable depth of field, the exposure is about three seconds on film with a tungsten speed rating of ASA 40 (Plus-X, etc.).

The rather crude construction of this test model leaves much to be desired, particularly in the quality of the lens, a simple four-element achromat. Precision construction, utilizing a more expensive lens, would bring considerable improvement. A major design defect which came to light during field use was the tendency for the camera to slip on the plexiglass plate during exposure whenever a few snow grains were caught between the plate and the camera frame. This can probably be corrected by the use of positioning pins to lock the camera and plate together during exposure. It would also be desirable to have a certain amount of enlargement, say 2X, take place within the camera itself, instead of having a 1:1 reproduction ratio as at present.

The construction and use of a camera designed along these general lines, utilizing precision parts, are to be highly recommended as a substitute for a microscope and photographic attachment when field use is planned.

Calorimeter

One of the instruments tested, though not used as an actual part of the snow study program, was a calorimeter designed for field use in determining the free water content of snow. The calorimetric method of determining free-water content is treated in detail in a recent SIPRE (1952) publication, and will not be described here, other than to state that it depends on the determination of the amount of heat required to melt the ice in a snow sample of known weight.

The most convenient form of calorimeter for this use is a vacuum bottle, a fragile item which requires rather careful handling in the field. It was for the purpose of providing a unit rugged enough to withstand field use and abuse that the instrument here described was designed. This calorimeter is pictured in Figs. 9 and 10. Basically, it is a wide-mouth vacuum bottle of sufficient capacity to handle snow samples from the standard 500 cc. coring tube, and mounted with foam rubber in a hardwood case. The case lid supports the dial thermometer, and is equipped with a gate which permits introduction of the snow sample without removing the lid. The method of introducing the sample in this fashion through a gate is based on a design suggested by Croce, as reported by Bekker (1951). Croce developed this design with the idea of eliminating the error caused by escaping water vapor when the snow was added to the hot water in the calorimeter, but it has been subsequently pointed out (SIPRE, 1952) that this source of error is insignificant.

A careful series of tests was made to determine the calorimeter constant, K, of this instrument. As this constant may vary with the manner in which the calorimeter is used, the steps in the determination of the constant, the same as would be taken in measuring free-water content of snow, are outlined here for the information of anyone who may be using this particular calorimeter in the future.

Since no balance of sufficient capacity was available at the time these tests were made, it was necessary to determine the calorimeter constant with the aid of volumetric measurements. A 250 milliliter (ml.) graduated cylinder was used for this purpose, and such errors in weight as would be introduced by this method were estimated as being small compared with those originating in reading the temperature from the dial thermometer. The procedure used was as follows:

1. Heat a sufficient quantity of water to 80-85° C.

2. Rinse out calorimeter and graduate with hot water.

3. Fit top to calorimeter and introduce 750 ml. of hot water as rapidly as possible.

4. Gently rock calorimeter once in each of four directions at 30-second intervals, recording temperature each time.

5. When temperature record shows equilibrium has been reached (4-5 minutes), quickly introduce 250 ml. of cold water (temperature 3-4° C.)

6. Again rock calorimeter at 30-second intervals until equilibrium has been re-established (1-2 minutes).

7. Read final temperature of mixture and compute calorimeter constant.

With careful attention to uniform technique, three successive determinations of K = 35.0 were achieved.

Because of its excessive weight and slow operation, the use of this calorimeter appears to be rather limited. Possible sources of error originating in design deficiencies are the small loss of heat through the thin bakelite gate in the lid, and difficulties in weighing due to retention of splashed water in the foam rubber padding. The present dial thermometer in the calorimeter is not the most accurate obtainable. It should be replaced with a Weston Metallic Testing Thermometer, Model 226-L-007, 0° to 100° C. range.

Where extensive work in free-water content determination is to be carried out, it would be advisable to use a number of smaller vacuum bottles, as suggested by SIPRE (1952).

Coring Auger for Snow and Ice

Among the equipment delivered to the ice field during the 1952 season was a hand-operated auger, with coring head, intended for use in firn and ice. This auger is based on a design drawn up by Maynard M. Miller, after consultation with European authorities, and was constructed by Loren Coolidge of Seattle, Washington.

The various parts of this auger, pictured in Fig. 11, have the following dimensions:

Length of coring head - - - - - - - - - - 1 m.

Effective coring length - - - - - - - - - 90.8 cm.

Outside diameter of coring head - - - - 4.3 cm.

Wall thickness of coring head - - - - - 3.17 mm.

Length of extension sections - - - - - - 1 m.

Diameter of extension sections - - - - 3.3 cm.

Swing of brace (radius) - - - - - - - - - 23 cm.

The coring head and extension sections are made of heavy aluminum tubing.

The auger was delivered to the ice field late in June by ski plane and was shortly thereafter put to test coring firn at Camp 10B as part of an effort to locate buried equipment. A further opportunity to test the auger occurred during an extended down-glacier trip early in July. On this trip, areas of exposed ice were reached and the auger was tested on hard, clear ice of density about 0.85. Early in August more tests were made on some exposed ice near the Camp 10 nunatak. This ice was of a very bubbly character and was easier to drill than that found lower down on the glacier.

From the results of these limited tests, the following observations may be recorded:

The large brace and the extension sections are sturdily constructed, and no difficulty was experienced in their use. The threaded joints are entirely adequate, and the system of wrenching for unscrewing the sections is satisfactory, although it would be more convenient to place wrench holes at both ends of each section, instead of at one end only.

It can be concluded with certainty, even from these few tests, that the coring head is rather unsatisfactory for obtaining firn cores, and is totally inadequate for use on ice. Firn (density about 0.5), was drilled without difficulty. In fact, the brace was not used, the coring head and extensions being turned by hand. Because of the thick walls of the coring head, considerable reduction of the collected snow sample's cross-sectional area occurred, accompanied by extrusion within the corer. As in the case of the density corer discussed previously, the amount of this extrusion varied with snow hardness, but in the case of the auger, was of much greater magnitude, reaching, on occasions, the point where the snow sample was extruded to a length equal to twice the depth to which the coring head was drilled into the firn. The deformation must be taken into account if the auger is used to determine the depth of icebands or dirt layers, the magnitude of given snow layers, or other sub-surface features. It was also extremely difficult to extract the firn core from the coring head, as the snow became tightly compacted by the compression described above. A core could be removed intact only after 15-20 minutes exposure to warm air, sufficient time for the characteristics of the sample to undergo considerable alteration.

In hard, clear ice the auger made very little progress even as a simple drill. In the softer, bubbly ice, drilling could be accomplished at the rate of about four m. per hour, at the cost of considerable expenditure of physical energy. It was necessary to withdraw the auger every few centimeters and clear the ice chips and fragments which became jammed in the coring tube and cutting teeth. In neither case could a continuous core of ice be obtained. The coring head simply collected broken chunks and cuttings until it was jammed full, and then failed to cut any farther until cleared. This difficulty arose from the thick walls of the coring head, necessitating the actual cutting of a large volume of ice, and from the total absence of any provision for carrying away the cuttings.

The problem of producing a satisfactory ice coring auger has been taken up during work recently conducted by the U. S. Army Corps of Engineers' Soils, Foundation and Frost Effects Laboratory (1950). A redesigned coring head could well be based on the designs worked out and reported by the above agency.

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FIELD STUDIES

Terminology and Techniques

It would seem appropriate at this point to introduce a short discussion of nomenclature to be used, before proceeding to an outline of methods. The definition of firn is of particular interest to this investigation, since lack of precision might lead to some confusion in presentation of data. Firn is a term often rather loosely applied (as has been the case on the Juneau Ice Field) to snow which has become dense and granular through a process of metamorphosis, generally prolonged. While perhaps acceptable when speaking in general terms of perpetual upland snow fields or accumulation areas of glaciers, such usage, leaving unresolved the exact point at which snow becomes firn, is inconvenient when dealing with snow profiles traversing depositions ranging from freshly fallen snow to material a year or more old. The inconvenience is perhaps a small one but the establishment of clarity warrants consideration. To this end this paper will follow the definition of firn as snow which has survived at least one season of ablation, a definition consonant with the etymology of the term and following the proposed usage of the International Snow Classification. A sharp line of distinction is thus possible between firn and snow, in this case the overlying burden of snow deposited during the accumulation season just past, and referred to in the particular instance of the work here described as the 1952 snow cover.

Working from the above definition, it follows that the firn line is the line on the glacier surface above which accumulation exceeds ablation in any given year. Thus the firn line, as we take it here, has a fixed position for any given year, but may vary its position on the glacier surface from one year to another. This corresponds to Glen's (1941) temporary firn limit (as distinguished from a developed firn limit established over a period of years), and Ahlmann's (1946) line of distinction between annual surplus and deficiency areas, a definition which is also followed by Sharp (1951a). Matthes (1942) likewise has adopted a similar definition of the firn line.

It has been the practice during past seasons of the Juneau Ice Field Research Project to refer to the line of demarcation on the lower reaches of the glaciers between glacier ice and annually deposited snow as the firn line. This irregular line, which retreats rapidly up-glacier during the ablation season, has been the subject of study by means of aerial photo records, particularly on the Taku Glacier. Ahlmann (1946) distinguishes this line from the annual firn limit, and describes it as the temporary limit between surplus and deficiency areas as determined at any given date during the ablation season. Since the line in question is that between ice and the annual snow cover, we cannot with precision apply to it the adjective firn according to the definition set forth here. It is therefore proposed that this line be referred to as the transient snow line, the modifying term transient being adopted to avoid confusion with the regional snow line as defined by Matthes (1942).

The general method of investigation employed in these snow studies was that of excavating pits at periodic intervals at a given site, and recording the snow characteristics as determined from measurements on the pit walls. When the records for the successive pits at a given site are compared, they afford an insight into the changes taking place within the snow cover. Work of this nature appears to have been carried out to a limited extent on glaciers by a number of observers. For example, attention is directed to the work of Ahlmann (1935) on Isachsen's Plateau, where density and grain size variations were recorded from pit studies. More recently, the studies of Wallen (1948) on the Kårsa Glacier of Swedish Lappland have included records of density variations as revealed by pit studies. The most extensive work of this type, however, appears to be that carried out by Swiss observers on transient winter snow covers with reference to the problems of avalanche study. In Switzerland, the interest in details of snow metamorphosis has led to a very careful study of a wide number of snow characteristics, such as temperature, grain size, grain type, density, shear strength, ram resistance, cone hardness, tensile strength, air permeability, and the interrelation of many of these. The Swiss have developed the practice of presenting data thus accumulated in a standard form known as the time profile ("Zeitprofil"), described by Haefeli, Bader and Bucher (1939). Continuous observations have been made since the late 1930's, resulting in the accumulation of a number of time profiles depicting the behavior of winter snow covers. These profiles, presented in a recent publication by Bucher (1948), constitute an excellent example of this type of display. In the United States, Work (1948) has used the time profile to display density and stratigraphic changes within a winter snow cover.

It has been the object of the work described in this paper to attempt emulation, in application to snow studies on glaciers, of these techniques established by the Swiss. The scale and accuracy upon which the observations were made have been quite limited by the lack of many instruments and cold laboratory facilities in the field. Presentation of the accumulated data has followed the form of the time profile, as will be found in the attached graphs. Data at some of the pit sites admittedly have been recorded for too short a period of time to yield much useful information on snow metamorphosis, but nevertheless are presented in time profile form for the sake of uniformity and comparison. In one instance a profile has been prepared by plotting snow characteristics versus distance along the glacier surface, a practice followed by Ahlmann (1935) and others.

The problem of selecting pit sites for summer observations on a glacier differs somewhat from selecting sites for study of a transient winter snow cover. Locating a level area away from the influence of terrain irregularities and rock outcrops was the least of the difficulties encountered on the Juneau Ice Field, where the predominant level expanses of ice cover a far greater area than the protruding nunataks. Selecting an area within a region of typical meteorological conditions is a more complex problem, complicated by absence of previous meteorological data over most of the ice field, and by local variations following from such phenomena as the distinct channeling of katabatic winds. The general area selected for each pit site was influenced by accessibility to travel throughout the summer, and proximity to aerially delivered supply dumps. Since no control checks were available from other locations, it cannot be stated with certainty that the sites selected were entirely representative of snow and meteorological conditions characterizing the surrounding areas. It is believed, however, on the basis of purely empirical observations, that they are at least reasonably representative. Avoiding snow cover irregularities introduced by hidden crevasses requires careful inspection of a site before excavation can begin. Even after the most careful selection, one pit site on the ice field was inadvertently located over a crevasse, but no change was made in the interest of securing information on the effects of a crevasse. A further factor over which the glaciological snow observer has no control is the stratigraphic irregularities introduced by the uneven surface underlying the snow cover. In the case of transient winter snow covers the ground on a selected study plot can be leveled and smoothed to keep snow deposition more nearly uniform. On a glacier the ground is replaced by firn or ice which has been exposed to ablation in the previous season, and has generally reached a maximum development of such irregularities as suncups when the succeeding season's snow cover begins to accumulate.

All measurements were made in metric units and are here so reported except for such occasions as it is necessary to express distances and altitudes in miles and feet to correspond with existing maps of the region.

Pit stratigraphy was measured with a 15-m. steel tape, graduated in centimeters. Readings were estimated to the nearest 0.5 cm.

Snow temperature was measured with two alcohol thermometers graduated from -100° to 50° C in 1° intervals. Temperature was estimated to the nearest 0.5° C. All measurements were made with the thermometers encased in metal thermometer armor tubes for physical protection.

Ablation readings were made at Camp 10A daily, at Camp 10B more irregularly, usually two or three times a week, and at the outlying sites, twice monthly. Ablation records were also maintained irregularly at each survey movement stake in the interest of gathering data over a wider area. Readings were made to the nearest 0.5 cm. whenever possible, but the average accuracy did not attain this figure with the frequent change in observing personnel, particularly at Camp 10A. On occasions records were interrupted through misunderstanding among the observers. The development of an automatic recording ablatograph for use on firn would be a desirable solution to such problems as this.

With the object of reducing subjective error, snow grain size and type have been recorded photographically for all pits examined, except in certain cases where the record was lost through equipment defects. Snow specimens were collected with the density coring tube at a depth of 25-30 cm back from the pit walls. Attempt was made to collect samples representative of each different snow type or layer exhibited in the stratigraphic sections. Levels at which a photographic record was made are designated by letter and number on the profiles. Because of limitations only the pit B series of photographs as copied line drawings are presented. These and the above profiles are at the end of this report.

Data presentation in the time profiles follows conventional practice as much as possible. Density and ram resistance curves are displayed together to the left of the axis. Immediately to the right of the axis is found the stratigraphic profile and a rough estimation of snow hardness according to the hand test. (See de Quervain, 1950.) Graphic and letter symbols follow usage of the International Snow Classification proposed by the Commission on Snow and Ice, International Association of Scientific Hydrology, (Schaefer, Klein & deQuervain, 1951) except for the symbol H_f, which is introduced to express height above the previous year's firn surface. Vertical positioning of the various graphs within the reference framework of a given time profile has been accomplished by setting the 1951 firn surface line of each graph to coincide with a reference line representing an assumed perfectly smooth surface. In actuality the 1951 firn surface possesses irregularities, and since each pit was displaced some 1.5 to 2 m. laterally from the preceding one at any given site, an error in the vertical position of the various graphs exists. Magnitude of this error does not exceed 20 cm. and is generally less. A similar error exists in the position relationship between the ram profile curve and the other characteristics. The improvised penetrometer was not suitable for use as a height scale for pit wall measurements, and the use of a measuring tape, though separated from the penetrometer by only a few centimeters in horizontal distance, often gave rise to differences originating in the firn surface irregularities. This error is less than 10 cm. in most cases.

The line on the time profiles labeled "snow surface" is a plot of surface level changes as measured with ablation stakes, i.e., a curve of gross ablation expressed in centimeters of snow. The snow surface is so plotted as to include the ablation stake record in a graphic form. The true change in surface level would be represented by a line connecting the surface points of the individual pit profiles. Reference level for this ablation plot is in each case established from the measured magnitude of the 1952 snow cover as exposed in the first pit in each series dug through to the firn.

In Profile I, pit site A, snow temperature versus depth is plotted for the first pit examined (A-1), since in this case sub-zero temperatures were observed. All subsequent pits at this site and others were found to expose only snow isothermal at 0°C, and for these, temperature has not been plotted.

Camp 10A, pit site A, was the only location where at least partial meteorological records were maintained, and such weather information as is available is presented in graphic form on Profile I.

Establishment of a uniform and efficient procedure of pit examination was necessary in the interest of saving time as well as to obtain consistent and comparable records. The travel schedule on the ice field involved other work besides that of snow studies, and dispatch in executing the observations was sought to enable most efficient utilization of the oversnow vehicle. The snow observer, usually assisted by one other member of the field party, carried out in most cases the excavation and examination of a pit in half a day. Required time for pit work of course diminished as the snow cover became shallower with progressing ablation. In two cases attempts were made to save labor by utilizing pits excavated for the purpose of retrieving buried equipment, but this must be regarded as rather a dubious practice from the standpoint of obtaining representative snow sampling.

Pits were almost always excavated by two men, and, with the deeper snow encountered earlier in the season, took the form of a stepped trench to minimize the required movement of snow. Short, D-handle shovels with pointed blades were found to be the most efficient for breaking up and moving hard snow. Temperature measurements were made at every 20 cm. interval as excavation progressed to insure reaching snow exposed for minimum length of time. During the latter part of the season, temperature observations were discontinued except for occasional checks to confirm that the snow was isothermal at 0° C. If extra persons were available to assist, the ram penetrometer test was carried out concurrent with excavation; if not, it immediately followed. The measuring tape was then arranged on the pit wall, and careful notes taken of the stratigraphy, grain size and type, hardness determined by the hand test, and such special features as icebands. The principal snow layers having been located, samples were then collected and photographed, with the snow camera situated in a niche cut into the pit wall for convenience to the observer and to shield the camera from either sunlight or precipitation. Observations were then concluded with density and cone hardness determinations, the two records frequently being made simultaneously when extra personnel were available. Intervals at which density samples were collected varied with the stratigraphy of the pit, with effort being made to collect samples representative of each of the different layers. Cone hardness measurements were spaced evenly at every 10 cm. interval from the surface to the bottom of the pit.

Profiles were completed and plotted after each return to base camp to display the collected information for immediate comparison and study in the field.

Program

Pit site locations occupied during the 1952 field season are displayed in an accompanying sketch map (Fig. 12) and reference to this map will clarify the following discussion. The intention here is to describe briefly the execution of the field work, and to describe observed phenomena which have not been suitable for display in the time profiles, or having been displayed, require amplification.

The summer snow study program was inaugurated on 27 May with the excavation of a 2.2 m. pit (A-1, Profile I) at Camp 10A on the surface of the Taku Glacier near the base camp nunatak. Though the base camp was reached by the advance party on 21 May, it was not until 27 May that shovels were delivered by free fall from a light aircraft and digging operations could be undertaken. The snow camera was also delivered at this time, and proved rugged enough to survive a free fall drop. Ablation records were started at the time of the first pit excavation, and were maintained, with only occasional interruptions, at Camp 10A throughout the summer.

The uppermost 60 cm. of snow in this first pit were coarse-grained and soft, reflecting the effects of warmer air and high values of diffuse solar radiation during the previous few days. From 60 cm. to 150 cm. (H_f = 340 - 250) the condition of the snow was firm and hard-packed, with numerous icebands. Below the 150-cm. level the snow was firm, homogeneous, fine-grained and free of ice structures. Below approximately 180 cm. (H_f = 220) the shovel started to ice up while digging and the thermometers froze in the snow. Measured temperature below the 180-cm. level was -1.0° C. At the time of excavation, this homogeneous lower snow layer, apparently a region still embraced by the winter cold wave and as yet free of intruding meltwater, exhibited no detectable evidence of iceband formation. On close examination some three hours after exposure, a number of fine, blue bands could be discerned in the previously undifferentiated snow layer. Probing revealed these bands to be soft, consisting of saturated snow layers. Further excavation into the side of the pit wall showed them to penetrate only 15-20 cm. into the snow. Beyond this distance the snow exhibited its original homogeneous condition. (See Fig. 13.) Careful modeling of the snow surface with a brush showed these bands to be forming just above thin layers of harder snow which were indistinguishable by visual inspection or casual probing. Fig. 26 shows the effect of modeling with a brush to reveal these harder snow layers. (This particular photograph was taken in a later pit.)

The next pit at Camp 10A was examined on 6 June. During the intervening period tests were conducted to find a more satisfactory type of ablation stake, and compaction measurements were attempted on the wall of the first pit. These lattor failed as a result of the rapid melting out of the wooden stakes used as markers. The pit of 6 June (A-2, Profile I) exposed only snow isothermal at 0° C. The homogeneous layers of snow which previously had been found to be below the freezing point at this time exhibited limited iceband formation. The snow as a whole was found to be considerably harder than in the pit of 27 May, and digging was more difficult, especially in the lower layers. It cannot be stated with certainty whether this increase in hardness occurred as a result of alterations taking place within the snow cover, or from the different location on the glacier surface, approximately 15 m. away from the first pit. The latter appears the more likely explanation.

The next pit at this site (A-3, Profile I) was excavated on 16 June. The snow was again found to be hard and cohesive, except for the top 50 cm. which had undergone considerable softening. The difficulty of digging in these early pits, as compared with those excavated later in the summer, offers at least a qualitative indication of changes taking place in the tensile and shear strength of the snow, characteristics for the measurements of which no instruments were available. It is believed that the tensile strength may undergo considerably more deterioration during the ablation season than does the ram resistance. Snow temperature in this pit was at 0° C. throughout, and a small, but general, increase in grain size appeared to be taking place following the dissipation of the winter cold wave. The west wall of this pit exposed an interesting example of the shielding effect of icebands on underlying snow, a phenomenon frequently observed in subsequent pits at other sites. In this case an undulating horizon upon which the iceband had formed created a series of small "anticlines," under which domes of hard, fine-grained snow were shielded from the degenerative effects which had reduced the surrounding snow to a softer and more coarse-grained structure. See Fig.14.

The next and fourth pit (A-4) at this Camp 10A site was not excavated until 11 July, since it was necessary to integrate snow studies with the schedule of other work initiated with the arrival on the ice field of the full summer field party. Observations in this pit will be described later in the proper chronological order.

Arrival on 24 June of the ski-wheel C-47 aircraft with additional supplies, plus the improvisation at this time of a ram penetrometer, permitted snow study expansion to include a wider range of tests. These additional tests, consisting of cone hardness, density, and ram resistance, were included for the first time in observations made in the first pit examined at Camp 10B (B-1, Profile II). Here advantage was taken of a pit already excavated for the purpose of exposing a wooden tower erected the previous season. Records were obtained to a depth of 2.3 m., with the ram penetrometer showing the 1952 snow cover to be 4.4 m. thick. The snow examined appeared to be more homogeneous and free of icebands than that at corresponding levels at Camp 10A. Subsequent probing around this site revealed this pit to be located in an anomalous pocket of deeper snow, and later pits of this series (B) were excavated some 100 m. away.

On 30 June a ski journey was made to the high branch of the ice field lying as a plateau to the north and west of the "Taku Range". Camp 9B was established at the site of an aerial supply drop and on 1 July a pit was excavated on the level snow surface about 1/3 mile SW of the camp site, and at an elevation of 4790 ft. The walls of the pit (C-1, Profile III) exhibited considerable variation in stratigraphy, one part being relatively soft, undifferentiated snow, while a meter away horizontally were numerous icebands interspersed with hard, fine-grained snow. Here again are noted the shielding effects of icebands on the underlying snow layers. The line of profiles was made in the softer snow, but later pits at this site all revealed iceband development, and the softer region must be considered the anomalous one. The density distribution was observed to be very uniform (see Profile III), as was the case in most instances investigated throughout the ice field.

Following return to the base camp, a second series of profiles was obtained at the Camp 10B site (pit B-2) on 5 July. Work was carried out in this instance on the pit wall exposed during excavation of the M29c oversnow vehicle. The practice of using pits excavated around buried objects for the purpose of snow observations cannot be recommended from the standpoint of obtaining sampling representative of normally deposited snow. In this case the press of time and manpower necessitated such practice, and the profiles obtained therefrom may be justifiably viewed with some suspicion. Except for the presence of icebands, the snow here was quite firm and homogeneous. Below the very heavy iceband the snow was particularly hard and cohesive. This heavy band found its maximum thickness near the point where the vehicle was buried, and it is surmised to have formed by meltwater collection along the surface of a wind scoop developed around the vehicle early in the accumulation season before it was completely buried. This was the first pit to reach the 1951 firn surface, and here was observed for the first time the soft, cohesionless layer of snow just above the firn surface which was later found to be a common feature of all the sites investigated. This snow appeared to be the result of depth hoar degeneration, and was the only layer in the 1952 snow cover which still retained traces of crystal facets and angles among the otherwise rounded grains. The steep temperature gradients within the snow cover required to produce the original depth hoar are most likely to have occurred early in the accumulation season.

By this time the oversnow vehicle had been placed in operation and a trip was made down the Taku Glacier to a point where bare and crevassed ice barred further travel. At the farthest down-glacier point reached, Camp 12A, pit D was excavated to a depth of 76 cm. overlying hard ice. At this point, elevation 1970 feet, approximately ¼ mile above the irregularly defined transient snow line, the snow was soft and wet, with little stratigraphic differentiation except for ice layers just above the glacier ice. On the return trip to Camp 10B, pits were dug and examined at two intermediate points, and soundings of snow depth were taken between these. Information thus obtained is plotted in Profile VI, with down-glacier distance as a base. It will be noted that the snow characteristics displayed in pit E, elevation

2450 feet, have similar features to those found lower down on the glacier, i.e., soft, wet and with little differentiation. Only a short distance up-glacier, however, at pit F, elevation 2750 feet, the snow is harder, more differentiated, and with greater variations in grain characteristics, although at this particular point the lowermost 30 cm. of snow just above glacier ice were inundated by a water table, with the snow thoroughly saturated for approximately 10 cm. above this by capillary action from below. Even the immersed lower layers of snow were hard and cohesive, but since the water table was observed to change level during the day spent at this site, it is possible that it had only just formed and had as yet had no opportunity to effect any large change in the snow.

It would appear that between pits E and F there must occur a fairly sharp line of demarcation between snow which has suffered almost complete degeneration and that which retains the hardness, cohesion and stratigraphic character established during deposition and subsequent metamorphosis. Pit D was dug on 7 July, pit E on 9 July, and pit F on 10 July. Taken together with pit B-2, 5 July, they represent snow conditions along the lower and middle part of the Taku Glacier as they existed shortly before the middle of the ablation season. Failure of the snow camera light source during this trip unfortunately made it impossible to obtain a satisfactory photographic record of snow grain characteristics for pits D, E and F.

On 11 July the next pit in the Camp 10A series (pit A-4) was investigated. This was the first pit at this site to be carried through to the 1951 firn surface, and the lower layer of the 1952 snow cover was found, as in the case at Camp 10B, to be soft and cohesionless, with general structure and appearance suggesting degenerate depth hoar.

Pit site G, (see Profile IV), elevation 4635 feet, was established on 12 July. This site was located approximately 3/4 mile NW of a low nunatak (Camp 8B) on the S bank of the large Taku tributary glacier which descends from a high divide on the Canadian border. Excavation of the pit revealed the snow type and structure to be very similar to that found at sites A and B. This pit was accidentally dug directly over a hidden crevasse in the 1951 firn. The crevasse was a small one, varying in width at the firn surface from a small crack to approximately 70-80 cm. It appeared to widen out at depth. In spite of the small aperture of the crevasse, a distinct sagging over perhaps 2-3 m. was exhibited by the layers of the 1952 snow cover. At the lowest part of the sag, meltwater had collected above certain impervious snow layers to form exceptionally thick icebands. (See Fig. 15.) The top surface of these bands appeared to be level and fairly smooth, as though a definite water table had formed. This was the case in a number of heavy icebands observed in other pits, which appeared to have formed from meltwater collected in depressions in impervious layers. Leighton (1952) observed iceband formation in the Juneau Ice Field snow cover and firn to be in the nature of bands with smooth under surfaces and irregular or undulating upper surfaces. This was often observed to be the case on a small scale in respect to the magnitude of the icebands, but does not appear to hold true on a gross scale, particularly for the heavier bands.

At this site the soft and cohesionless layer of snow just above the 1951 firn surface was observed to be present in about the same magnitude and form as at sites A and B.

On 14 July travel was continued up this same branch of the Taku Glacier, and a camp was established near the Canadian border at an elevation of 5915 feet. Excavation of a pit (H-1) was begun that afternoon and carried on through the next day, reaching a depth of 7.5 m. No positive indication of the line of demarcation could be found by visual inspection. The snow was quite homogeneous in grain characteristics and hardness, except for a soft 50 cm. at the surface and the presence of numerous icebands and pipes. The ice structures were more prominent than in the pits examined at lower elevations, but the snow itself showed less evidence of degenerative metamorphosis. Grain characteristics were quite uniform throughout the depth of the pit, with irregular and angular grains predominating and showing considerable variation in diameter in any given sample. An increase in snow hardness occurred below about 5.3 m. down from the surface, but no other appreciable change in the character of the snow was ascertainable with the instruments at hand except density, which showed a low value just above this 5.3 m. depth, and was thought to correspond with the soft and cohesionless snow of low density observed at the bottom of the 1952 snow cover in other pits, thus tentatively establishing the 1951 firn surface at approximately 5.3 m. below the surface. This evidence of the line of demarcation was not considered conclusive because of the absence of any difference in snow grain characteristics, but later plotting of the ram profile showed that a sharp and clearly defined increase in average ram resistance occurred at a depth of 5.2 m., and this latter figure has been adopted as the 1952 snow cover depth on 15 July for the purpose of plotting Profile V.

Return to the base camp was made by way of Camp 9B, where the second pit at site C was excavated on 17 July, this time through to the 1951 firn surface at a depth of 3.32 m. The soft, cohesionless layer of low density was again found just above the firn, though not so clearly defined as at sites A, B, and G. This would appear to be a widespread feature of the 1952 snow cover, and apparently is an annual occurrence, having been observed on the Juneau Ice Field in a similar form in snow covers of previous years (Miller, 1952). The ram profile taken during the study of this pit was carried to a depth of 4.7 m., and indicates that the 1950 firn surface may have been reached at 4.58m. Lack of time did not permit further excavation to confirm this surmise.

During the excavation of pit B-3 on 19 July, following return to the base camp, it was discovered that two of the holes left by the 1/3-in.rod used to probe for the buried snow vehicle some three weeks earlier fell within the area of the pit. Both holes retained their original size and were surrounded by a sheath of hard, bubbly ice of wall thickness approximately 1 cm. Line of demareation between the ice sheath and the surrounding snow was very sharp. The ice sheaths continued unchanged for the entire depth of the holes, which terminated a few centimeters above the 1951 firn surface.

The subsequent snow behavior as observed during later study at the various pit sites is recorded in the accompanying time profiles, and no attempt will be made here to include a complete description of each pit. Attention is, however, directed toward the behavior of the 1951 firn as shown in the later pits, where evidence of progressive softening and degeneration is apparent in the upper layers, even though they are still shielded by the overburden of snow.

Conclusions

The season of field work reported in this paper cannot be regarded as entirely original effort, but rather as a continuation of research carried out on the Juneau Ice Field since 1949. The principal contribution here has been made by a more concentrated study of the snow cover to the exclusion of the underlying firn, and by undertaking observations over more widely scattered regions of the ice field than done in previous years. The more important conclusions to be drawn from the data accumulated during the 1952 field season are presented in the following paragraphs.

One of the first characteristics which becomes apparent upon examination of the profiles is the remarkable uniformity of snow density in vertical profile, in distribution over the ice field, and with time. The average density from fifteen pits dug completely through the 1952 snow cover is 0.51 gm/cm^3, and it will be noted that the density curves show very little departure from this mean value except for the previously mentioned layer of low density just above the firn. Lack of access to records from work in previous seasons on the ice field makes it impossible to judge whether this is a normal condition, or represents a peculiarity of the 1952 snow cover. It might be noted, however, that Sharp (1951a)reports considerably greater density variations for the snow cover on the Seward-Malaspina glacier system farther to the north along the Alaskan coast.

Such features as grain size and type, ram resistance and number and distribution of ice structures also exhibited wide uniformity, though not to such a degree as density. This general homogeneity of the snow cover might in part be anticipated from the maritime nature of the Juneau Ice Field climate, with its frequent heavy snowfalls during the accumulation season.

The location of pit sites on widely scattered parts of the ice field has yielded information which should make possible the more efficient selection of sites for future snow observation. The general character of the snow cover was quite similar at sites A, B, C and G, though site C appeared to have snow which was slightly less advanced in firnification. Site H, at 5915 feet elevation, exhibited a distinctly different character with a much heavier snowfall. Sites D, E and F fell below the firn line. A single site located perhaps 3 to 4 miles up-glacier from the present base camp would probably be reasonably representative of snow conditions on the Taku Glacier drainage basin between the elevation of the firn line and that of perhaps 5000 feet. The high Camp 8 area (site H), though of smaller extent, appears to have sufficient individuality of climate and snow to warrant separate study. Since these observations were made on only a single year's snow cover, the possibility of a different distribution in other seasons cannot be discounted. One important tributary drainage basin of the Taku Glacier, that in the vicinity of Camp 15 on the NW part of the ice field remains yet to be studied in the light of snow conditions.

Mention has already been made of the soft, cohesionless snow layer of low density just above the 1951 firn surface. The degree of regenerative metamorphosis which this layer underwent during the winter cannot be estimated accurately, since degeneration had already set in by the time it was first examined, and its character could be deduced only from an occasional crystal angle or facet occurring among the snow grains, and from its physical structure. The latter especially points to a heavy formation of depth hoar with its characteristic cohesionless structure, but no positive evidence of depth hoar crystals remained. Particular attention in this report has been accorded this soft layer, since it provides a useful clue to the snow cover depth, and if, as reports indicate, it is an annual feature of the snow cover, it should provide a convenient key for locating annual horizons within the firn by means of ram profiles.

The shielding effect of ice bands on the underlying snow layers has been noted in several specific cases during discussion of the field work. During the course of the season's work it was repeatedly observed, purely on a qualitative basis, that this shielding was a universal phenomenon varying in given instances only in degree. The lower layers of the snow cover were noted to retain their hardness and grain character to a large degree throughout most of the ablation season. It was only near the end of the observation period (after mid-August), when snow depths at sites A and B approached one meter, that strong degeneration began to be evident in these lower layers. This is believed to be due at least in part to shielding by the heavier continuous icebands in the snow cover, which apparently serve to retard degeneration by obstructing the intrusion of warm air and percolating meltwater. No quantitative data are available to substantiate this thesis, but Leighton's (1952) observations of icebands as a deflecting agent in meltwater flow would seem to confirm it in part. If this shielding is actually as extensive as it appears, the presence of icebands in the snow cover would seem to be an important factor in glacier economy, since they would have some effect in retarding the ablation rate. The wet and degenerate nature of the snow in pits D and E may possibly be due in part to the observed absence of even moderately heavy icebands as well as the lower elevations (see Profile VI). Note that pit F, though only 300 feet higher in elevation than E, shows much stronger iceband formation, and, along with it, harder and less degenerate snow structure.

Whether this line of demarcation between sites E and F is due to this difference in iceband structure, to the configuration of the glacier, to changes in weather conditions with elevation during the ablation season, or a combination of these factors, cannot be stated with certainty from the scanty evidence at hand. If it is primarily the result of different rates of ablation at different elevations, then it might be expected to advance up-glacier during the ablation season at some irregular distance ahead of the transient snow line. If it is due to the shielding effect of icebands which found heavier formation above a certain altitude following certain meteorological conditions at the start of the ablation season, or is a peculiarity of glacial geography, then it would probably remain stationary. Completion of a sequence of such profiles as Profile VI should yield information on this point.

Leighton's (1952) observations of icebands as a deflecting agent for downward-percolating meltwater were further confirmed by the presence of very heavy bands in what appeared to be depressions in impervious horizons. Presumably the meltwater flowed horizontally along these horizons, or along thin icebands already formed over them, and collected in depressions and froze to form heavy icebands or lenses. Pit G-1, Profile IV, and pit B-2, Profile II, exhibit excellent examples of this formation, one where the depression was formed by the snow cover sagging over a crevasse, and the other where it was apparently formed by a wind scoop developed around a partially buried vehicle.

It will be noted that in all the time profiles a discrepancy exists between change in snow surface level as determined from cumulative ablation records and that determined by actual measurement of the snow cover magnitude on the pit walls. In the interest of clarity, this information has been plotted separately in Figs. 16,17,18,and 19. The problem of determining the significance of this discrepancy must be approached with some caution, since it could be readily introduced by errors in ablation measurements or variations in snow depth along the line of pit profiles. In view of the fact that the discrepancy appears consistently and of the same sign in records over a period of 2½ months from four widely separated sites on the ice field, it would seem that the latter could not be responsible. Variations in magnitude do appear, and may in part be attributed to ablation measurement errors arising from differential settling of ablation stakes. At site A for most of the season, and B for the early part of the season, short stakes of 1-1.5 m. were in use, and may have contributed to a larger discrepancy at these sites. At sites C and G, stakes were implanted 2.5 - 3 m. deep and presumably suffered minumum differential movement. If the gross ablation measured at the stakes is reduced to mm of water by assuming a surface snow density of 0.5 gm/cm^3, a comparison is possible with the actual net water equivalent loss of the snow cover as determined from the pit density profiles. This comparison is made graphically in Figs. 20,21,22, and 23 for the four principal pit sites. These graphs show that in all cases the net ablation was equal to or greater than the gross ablation of the 1952 snow cover. Wallen (1948) observed that on the Kårsa Glacier of Swedish Lappland gross ablation exceeded net ablation, just the reverse of the relationship noted here, but whether this arises from an actual difference in the ablation processes, or from errors in the Juneau Ice Field observations, must await the acquisition of additional data during future seasons of the project. If the data presented here are accepted as valid, then it would appear that a small loss of water content must occur throughout the snow cover. That sub-surface changes are being wrought during the ablation season is clearly demonstrated by the progressive softening of the 1951 firn surface, even though it is shielded at all times by the snow cover. This may be readily discerned in the ram resistance curves of Profiles II, III, and IV. It is somewhat obscured in Profile I by position errors of ram depth in respect to stratigraphy, but the progressive softening of the underlying firn was noted during excavation as it was at the other pit sites.

Mention has already been made of the difficulty encountered in determining the 1951 firn surface level at the Camp 8 (H) site. The depth of the 1952 snow cover over firn was ascertained mainly from study of density and ram profiles. The difference between snow grain character and size of the current snow cover and that of the firn below was so negligible as to make location of the line of demarcation uncertain on this basis. This lack of sharp distinction may be attributed to the short ablation season occurring at this altitude (5915 ft.). When the first pit (H-1) was dug on 15 July, it was immediately after a heavy snow fall. How much ablation occurred prior to this date is unknown, but was probably considerably less than on other parts of the ice field, since precipitation which fell as rain at lower elevations often fell here as snow. The second pit (H-2) was examined on 15 August in the midst of a blizzard which subsequent meteorological records show to have terminated the summer ablation season. It would seem that a short ablation period, broken by snowfalls, would result in less degenerative metamorphosis of the snow, and consequently in less differentiation between old snow (firn) and new. On 15 August the 1952 snow cover depth at this site was 4.18 m. in what was apparently a near normal year. (Since the only other records accessible at present are those for 1949, the judgment of normality has been made from verbal information obtained from project members who were on the ice field in previous seasons.) On this basis the Camp 8 district of the Juneau Ice Field must make a considerable annual contribution to the economy of the Taku drainage on the west and the Llewellyn drainage on the east in spite of its relatively small area.

One useful contribution of snow studies on a glacier is the estimation of the annual accretion of material to the glacier economy in the form of the snow cover. This accretion as measured in the snow cover alone cannot give the overall net accumulation, for it does not consider factors such as the retention of percolating meltwater in the underlying firn, but it yields at least a minimum figure of use in estimating the glacier economy. In the case of sites A, B, C, G and H, all lying above the 1952 firn line, information is available about the snow depth and water content of 1952 snow cover for the period 13-23 August. Meteorological records maintained by the late-season field party indicate that the ablation season probably ended on 5 September. Direct ablation measurements at Camp 10A were carried out through 5 September, and showed the average ablation rate for the period 23 August - 5 September to be approximately one-third that during the first part of August. This reduced rate occurred as a result of cold and stormy weather. Extrapolating the ablation rates at the other sites at one third their rate during early August should lead to at least an approximation of the snow cover depth at those sites on 5 September. On this basis (with ablation at site H observed to have ended on 15 August) the following annual accumulation figures for 1952 may be obtained. The water equivalent is determined by extrapolating the ablation rates in mm of water from the known values of water content in the last pits examined.

Site	1952 Accumulation	
	cm snow	mm water
A	116	575
B	132	685
C	205	1090
G	218	1125
H	418	2180

The problem of accurately measuring accumulation in terms of water equivalent of a snow cover deposited over wide and irregularly distributed glacier areas is one that frequently confronts the glaciologist. The total accumulation, expressed in cubic measure of water, is a term of the equation of glacier economy, and is dependent upon accurate knowledge of area of the glacier surface involved in the accumulation zone, and upon representative sampling of snow cover water content from as many points within this area as possible. In this modern day of aerial mapping the glaciologist often has at his disposal a map or aerial mapping photos from which he can determine the extent of the accumulation zone to a degree of accuracy sufficient for the estimation of glacier economy. The second problem, representative sampling of water content, has often proved an obstacle to accurate accumulation records (see, for instance, Wallen, 1948), inasmuch as it has been necessary to excavate a pit, a time-consuming process which severely limits the number of points which may be sampled. Snow surveys on transient winter snow covers overlying earth instead of firn or ice have long been made with sampling tubes, such as the Mt. Rose Snow Sampler, which permit direct determination of water content. The use of these sampling devices on a glacier is frequently limited by uncertainty about the depth of the snow-firn dividing line, and hence the necessity of digging pits. If a method for accurately locating the snow-firn division without excavation were available, then the glaciologist would be able to use a sampling tube, and, freed of the necessity of pit excavation to ascertain water content, could increase many times the number of sampling points and the accuracy of his accumulation figures. The experience gained during the 1952 field season on the Juneau Ice Field has led to the conclusion that the ram penetrometer (Haefeli Rammsonde) offers a solution to this problem. Examination of the accompanying time profiles will show that in every individual profile where a ram resistance curve was obtained, a distinct and unmistakable increase in average ram resistance occurs as the penetrometer passes from snow into firn. Even in the case of pit site H, where the snow-firn line was in doubt even after visual inspection of the pit wall, evidence offered by the ram penetrometer appears to be conclusive. The suggestion might therefore be made that a ram penetrometer and a sampling tube, such as the Mt. Rose model, would usefully augment the glaciologist's equipment. With instruments of suitable design and length, it is conceivable that more than one annual layer could be penetrated and accumulation figures for more than one season be obtained.

Recommendations

As snow studies will probably be an integral part of the Juneau Ice Field Research Project in future years, as it has been in the past, it would be appropriate to conclude this discussion with a few suggestions based on the experience gained to date.

If a program of pit studies to obtain time profile data is planned for future seasons, it would probably be more profitable to concentrate on one representative site (See Conclusions, above) with pits at more frequent intervals, say, ten days, for as long a period as possible. It would be very desirable to initiate the study early enough to observe the winter cold wave dissipation, an objective which was sought this season, but which was just missed. If the schedule permitted occupying a second pit site, then the Camp 8 region should prove a fruitful area for investigation.

Profiles made along a line in the glacier surface, such as Profile VI, would be of greater value if repeated at intervals to permit snow characteristics to be plotted as a function of time as well as depth and distance. Such a line of profiles across the firn line might prove informative, as would one from Camp 8 down-glacier to an elevation of perhaps 4500 feet.

One of the long-range objectives of the Juneau Ice Field Research Project has been to seek an explanation of why the Taku Glacier has been advancing since the turn of the century, while nearby glaciers with similar terrain and climate have been retreating. Observations to date have understandably been concentrated on the drainage basin of the Taku Glacier itself, but before a complete analysis of the problem can be undertaken, it would seem advisable, at least to this writer, to make a control study of one of these nearby normal, i.e., retreating, glaciers, such as Norris or Lemon Creek.

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FIG. 1—Ablation stake of 2 x 2 in. wood painted white, 24 hours after implanting 30-40 cm. Ablation crater diameter is about 15 cm.

FIG. 2—Ablation stake of unpainted hardwood dowels two weeks after implanting. Ablation crater is only 7-8 cm. in diameter. Note contrast with Fig. 1.

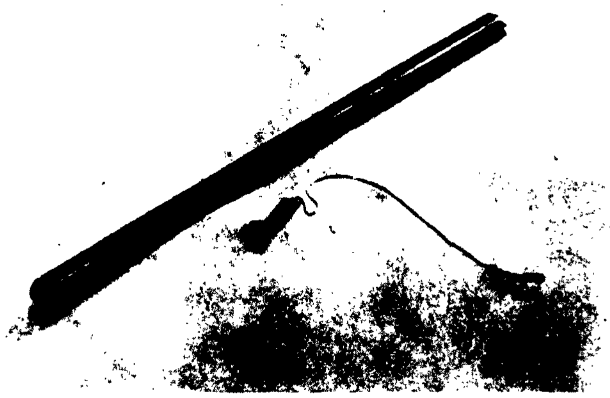


FIG. 3—Density coring tube. Small metal plate fits into the slot seen near the right-hand (toothed) end of the tube.

FIG. 4—Cone hardness gauge in operation. Operator's left thumb rests on the release trigger.

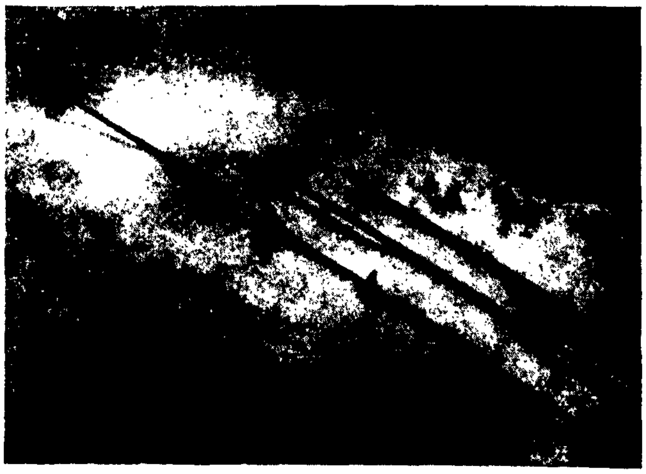


FIG. 5—Improvised ram penetrometer. Lower section has the wooden guide rod and the ram weight; the upper section shows the point.

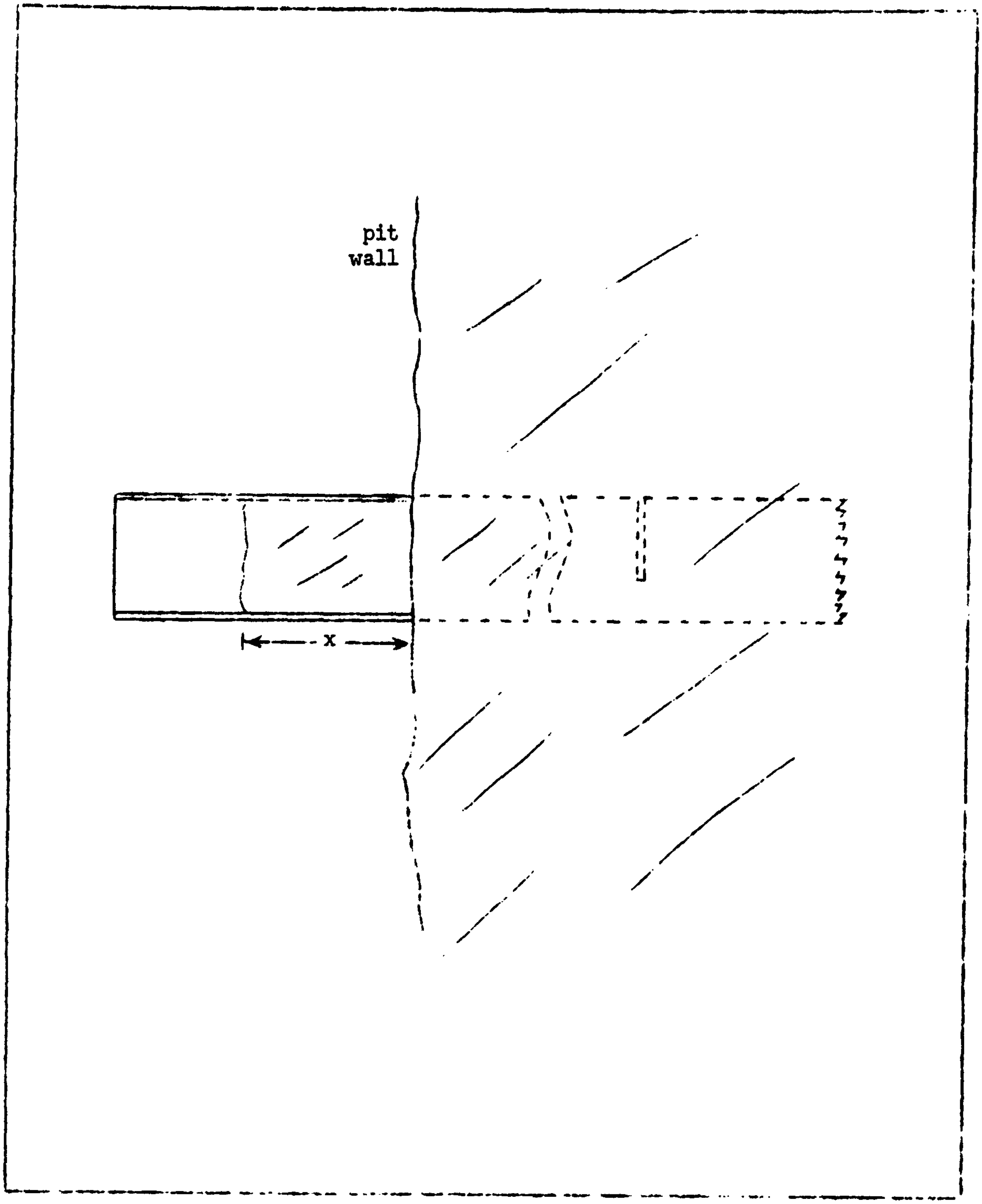


Fig. 6 - Cross-section of density coring tube, showing extrusion of snow sample occurring as tube is inserted in the snow. Magnitude of extrusion, x, varied from 0 to about 5 cm. for the various types of snow observed. Sketch not to scale.

Fig. 7—Experimental snow camera. Black plate is a sheet of plexiglass used as a background for photographing the snow samples.

Fig. 8—Another view of the snow camera, showing the arrangement of the flashlight bulb as a light source.

Fig. 9—Calorimeter for determination of free water content of snow.

Fig. 10—Calorimeter with top removed, showing the rubber-mounted, wide-mouth vacuum bottle.

Fig. 11—Hand-operated coring auger for use in firn and ice. Illustrated are the brace, extension sections, coring head, and screw drivers used as wrenches.

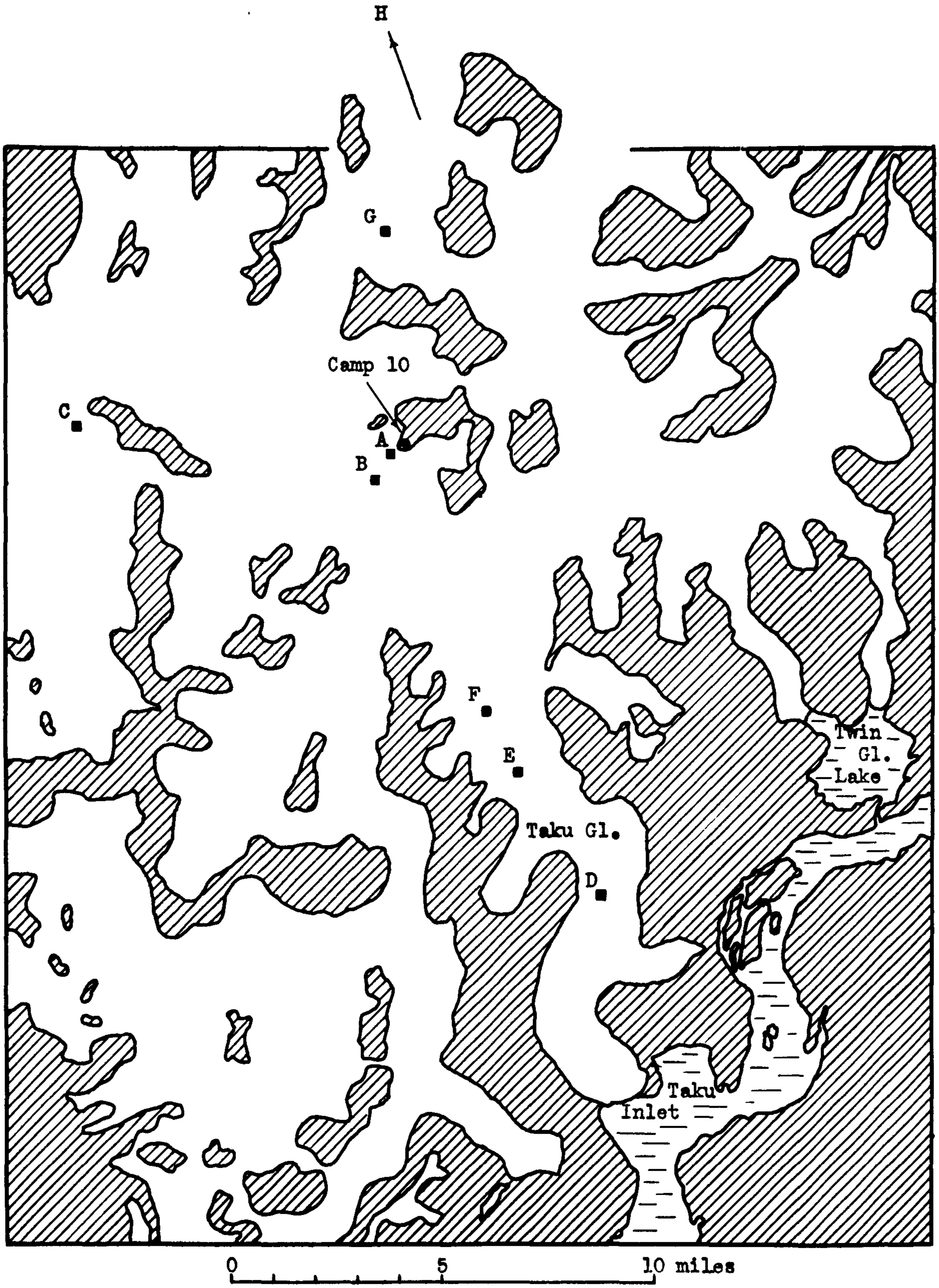


Fig. 12

Sketch map of the Juneau Icefield, showing location of snow research pit sites.

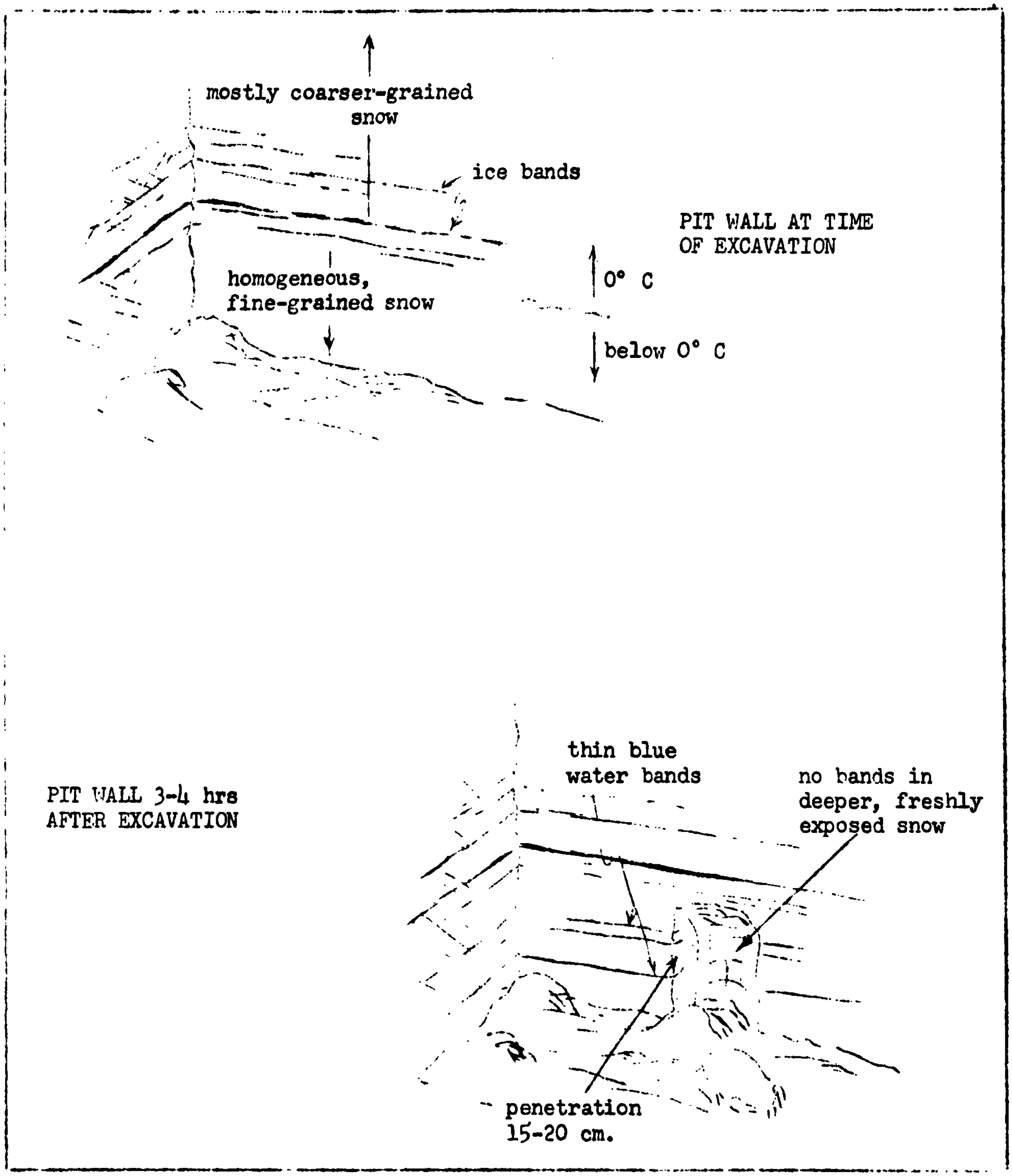


Fig. 13- Sketch showing incipient formation of icebands following dissipation of winter cold wave, as observed in pit A-1.

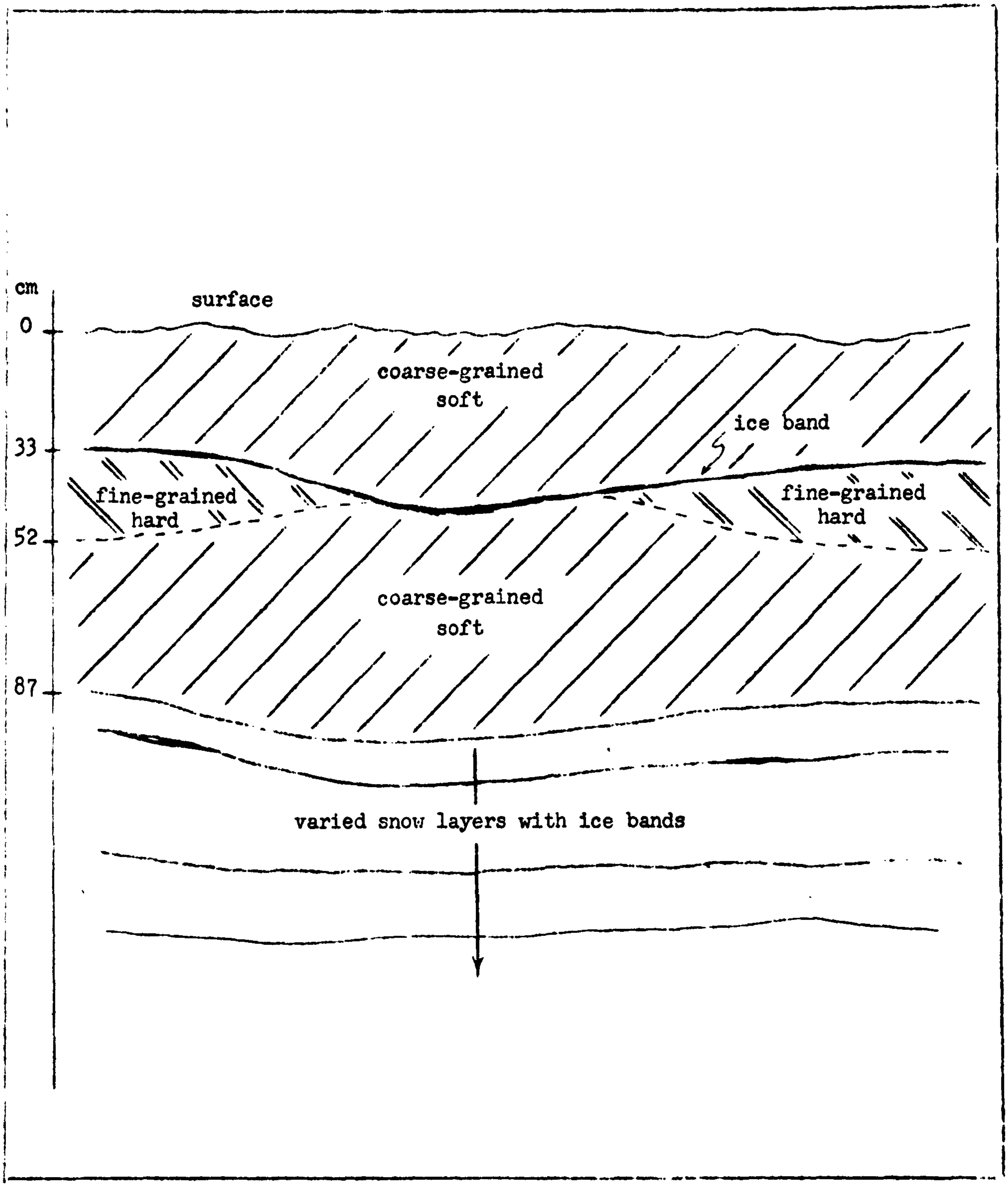


Fig. 14 - Sketch showing shielding effect of icebands on underlying snow, as observed in pit A-3.

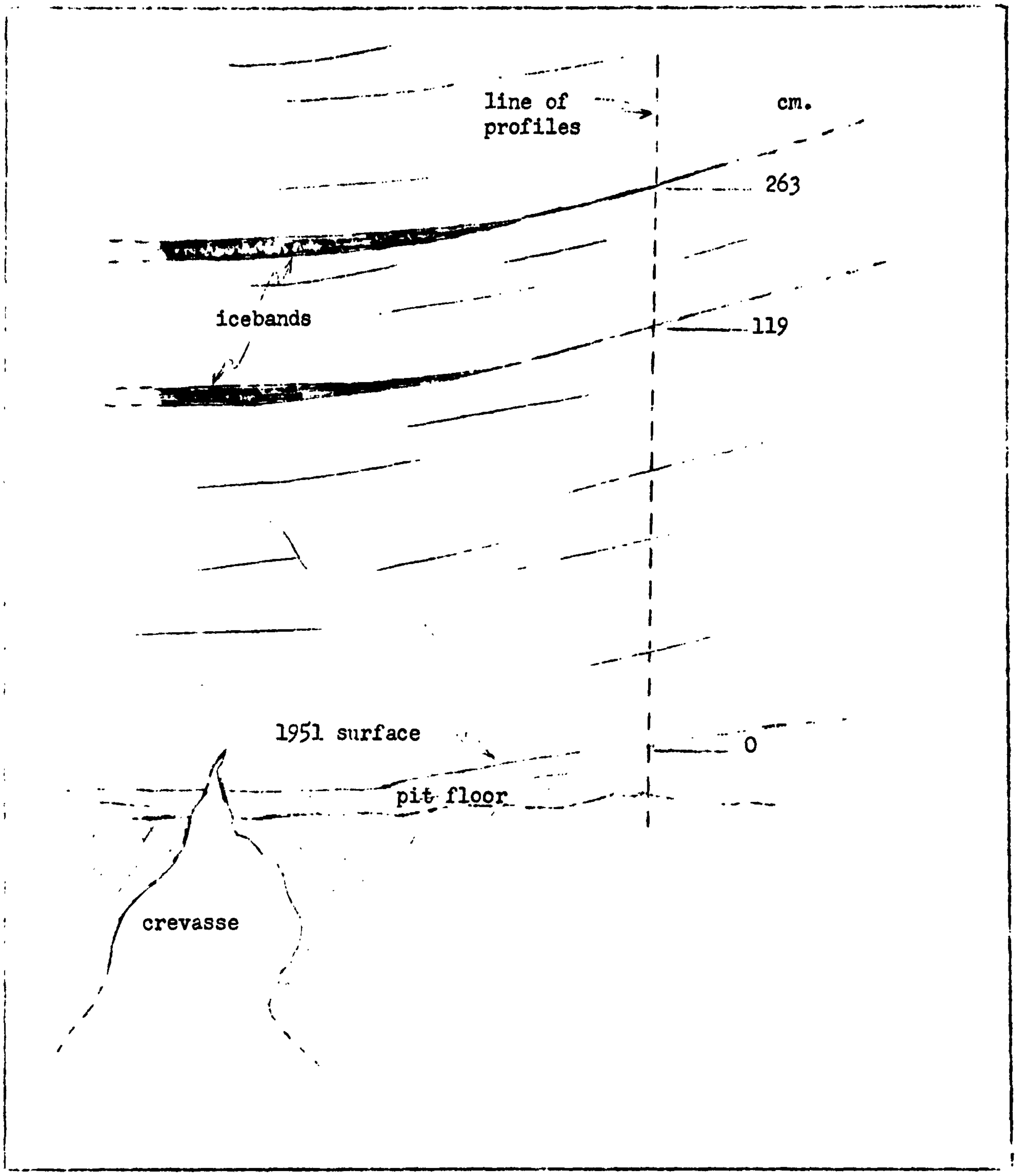


Fig. 15 - Sketch showing heavy formation of icebands where dip in snow strata was formed by sagging over a crevasse. Sketched from wall of pit G-1.

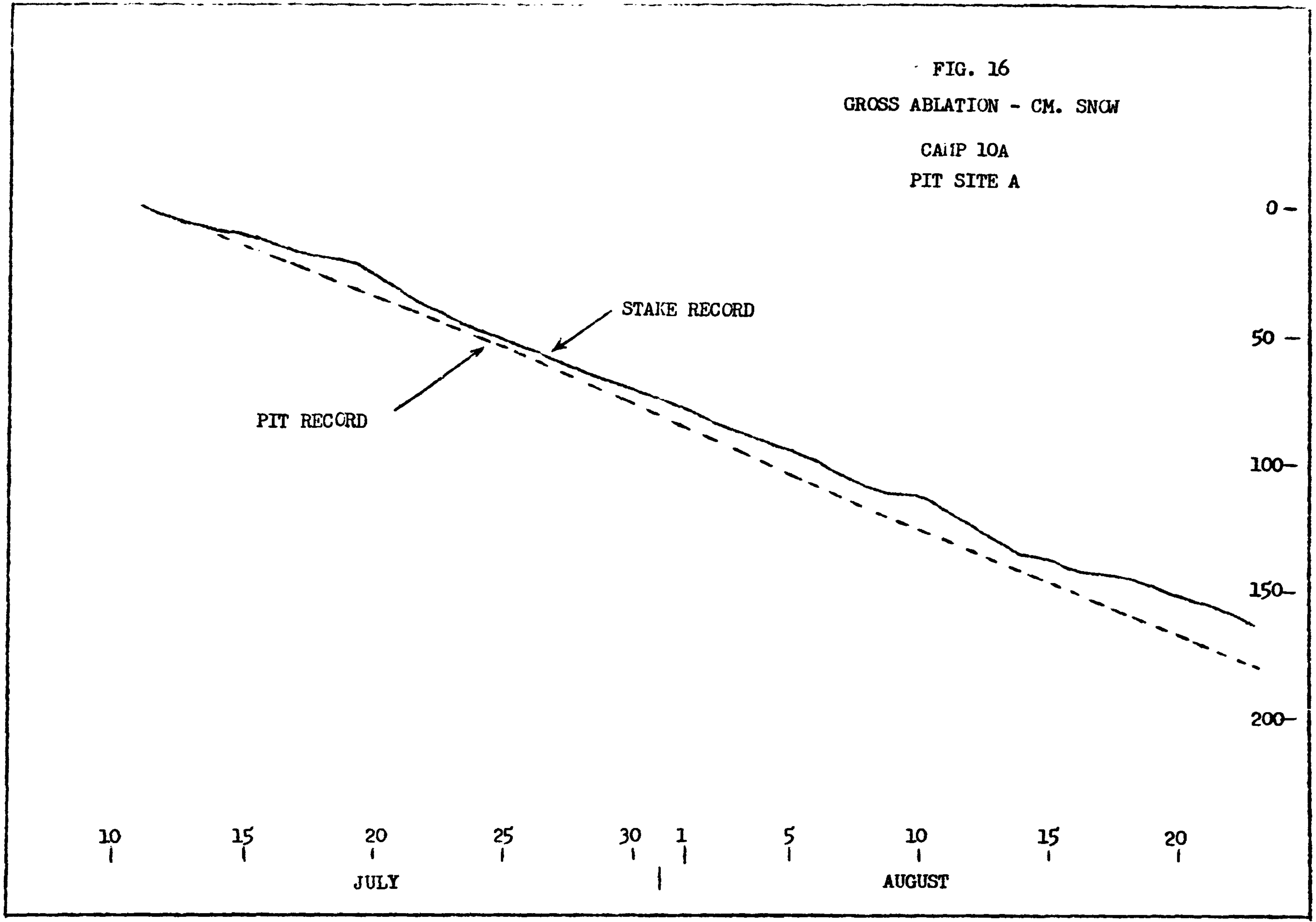


FIG. 16
GROSS ABLATION - CM. SNOW
CAMP 10A
PIT SITE A
STAKE RECORD
PIT RECORD
0
50
100
150
200
10
15
20
25
30
1
5
10
15
20
JULY
AUGUST

FIG. 17
GROSS ABLATION - CM. SNOW
CAMP 10B
PIT SITE B

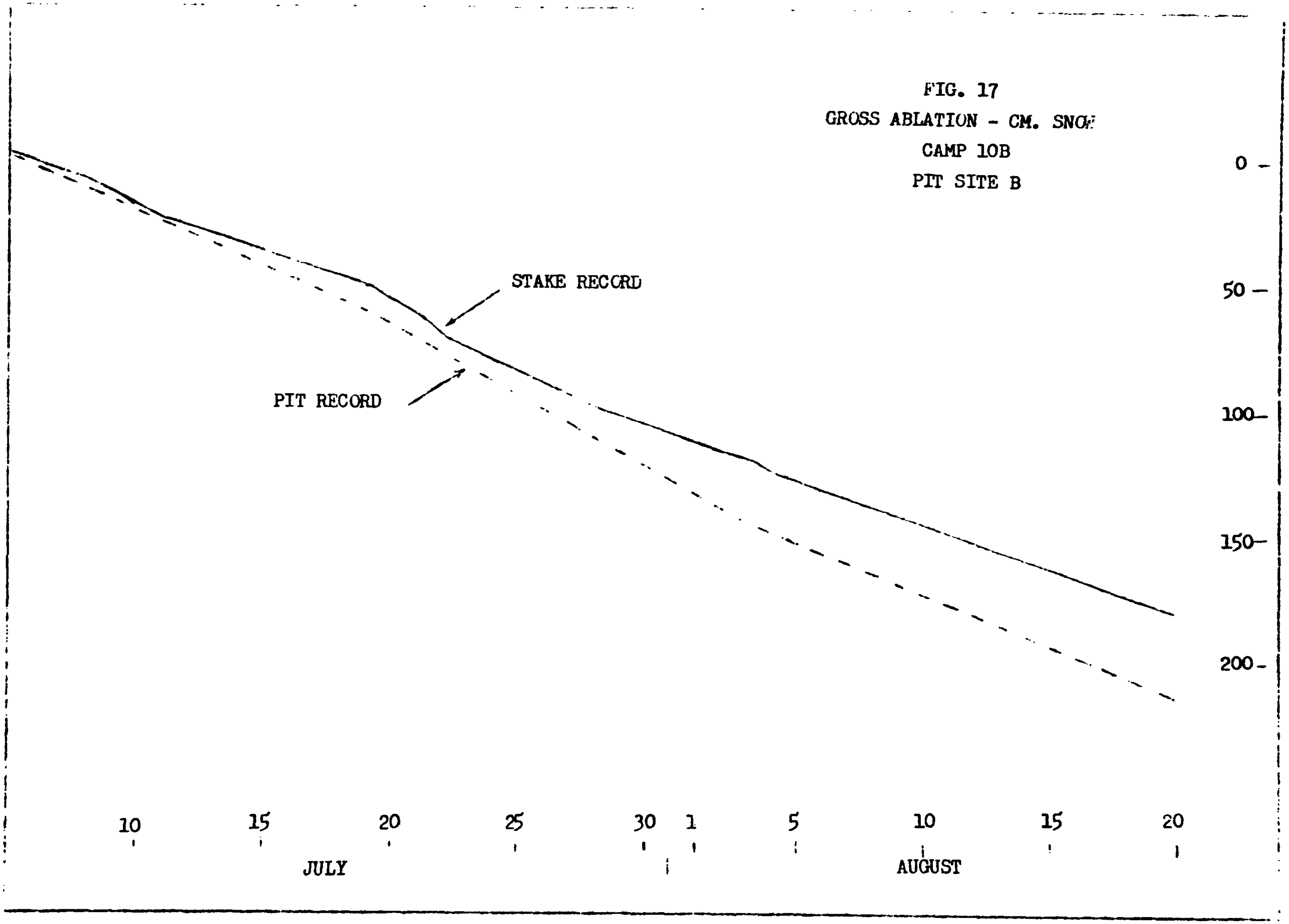
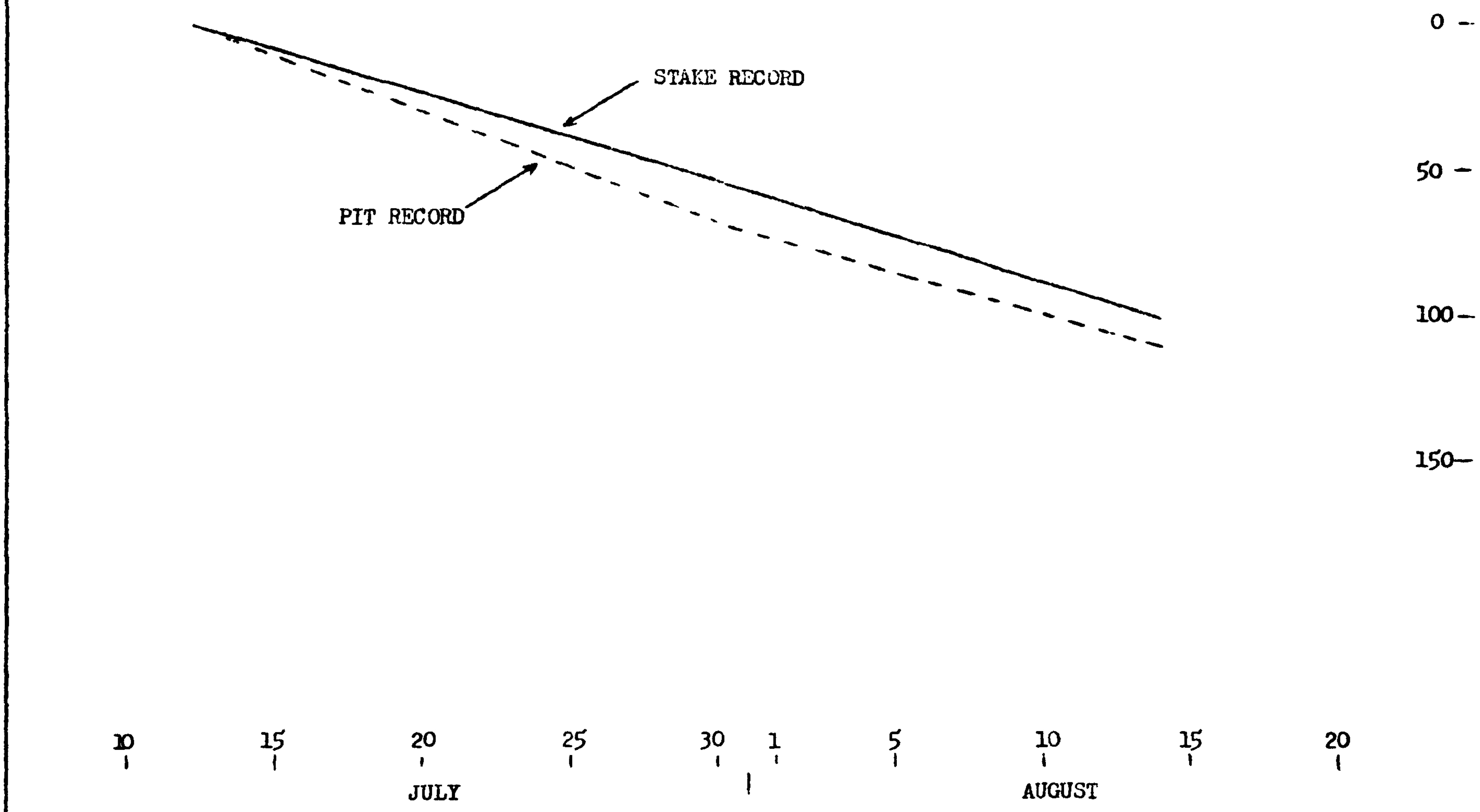


FIG. 18

GROSS ABLATION - CM. SNOW

CAMP 8B

PIT SITE G



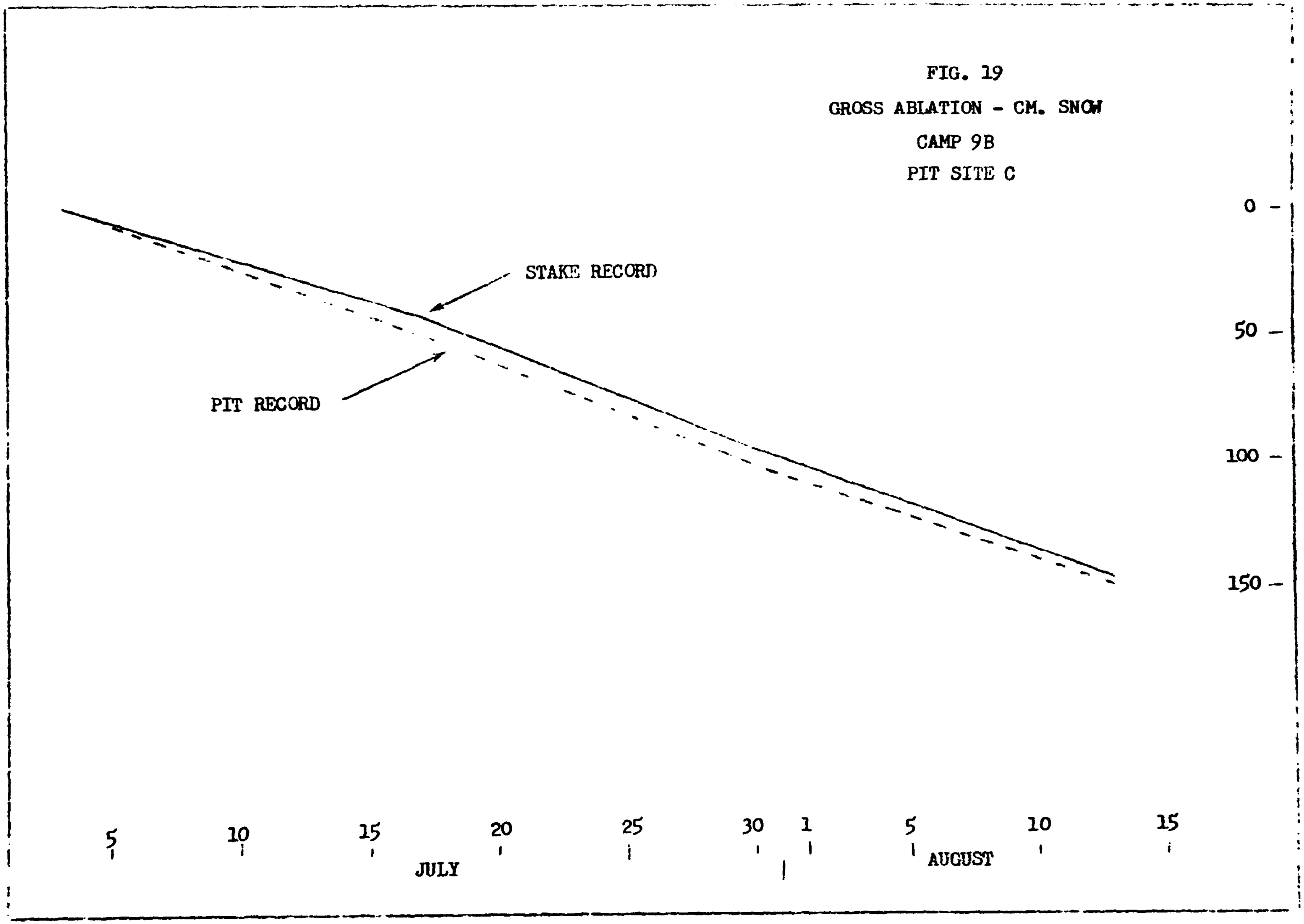


FIG. 19

GROSS ABLATION - CM. SNOW

CAMP 9B

PIT SITE C

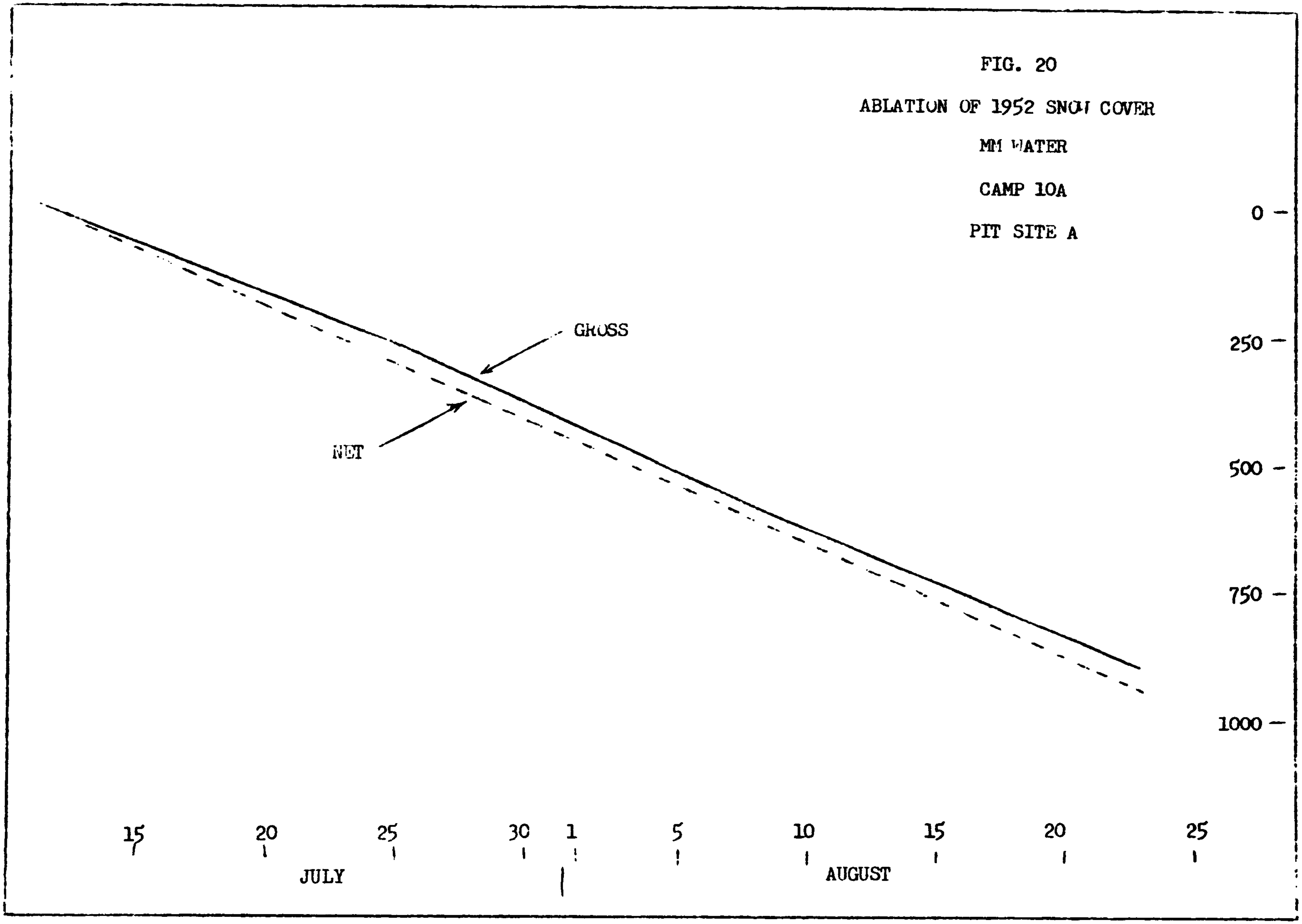


FIG. 20

ABLATION OF 1952 SNOW COVER

MM WATER

CAMP 10A

PIT SITE A

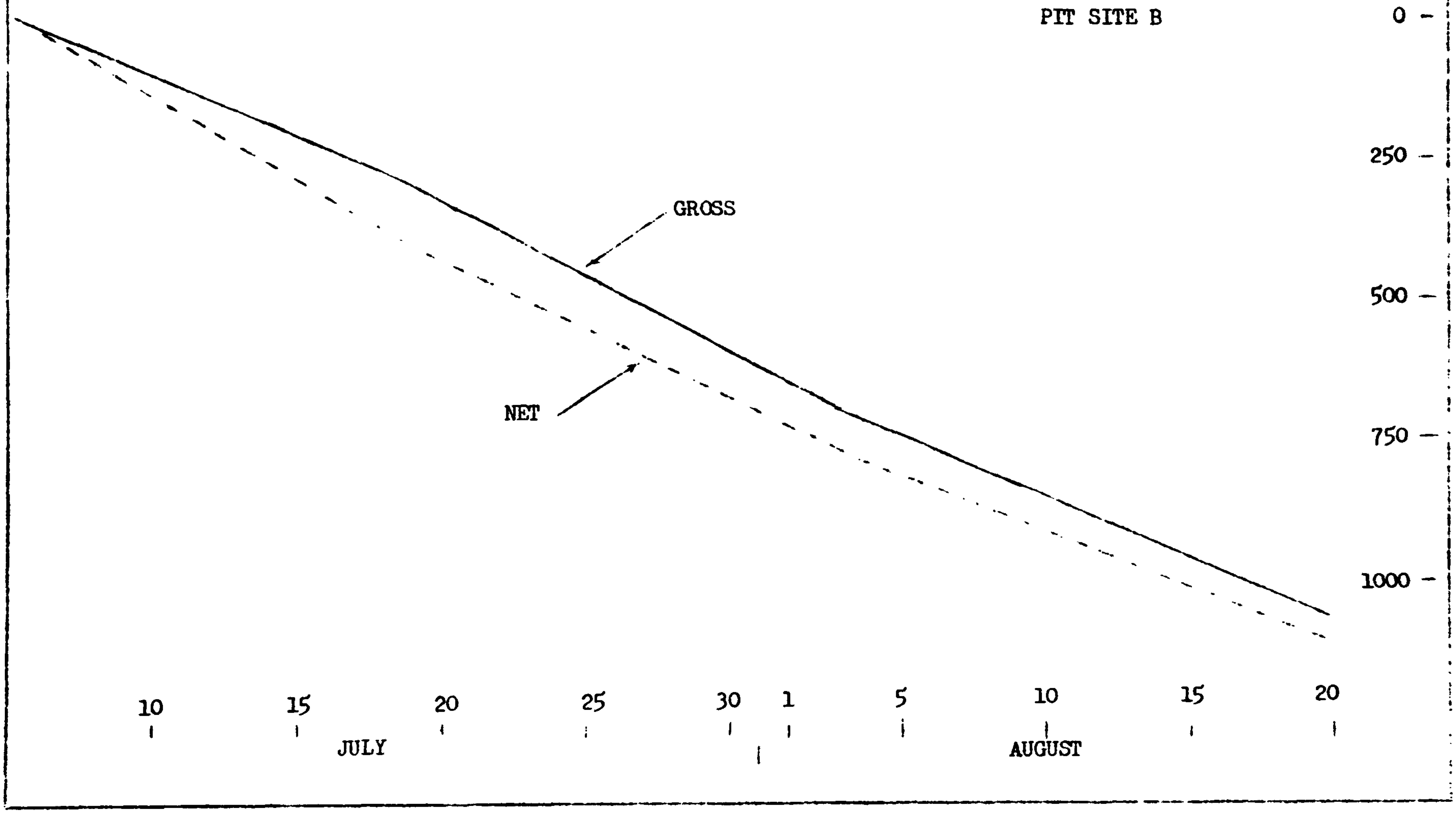
FIG. 21

ABLATION OF 1952 SNOW COVER

MM WATER

CAMP 10B

PIT SITE B



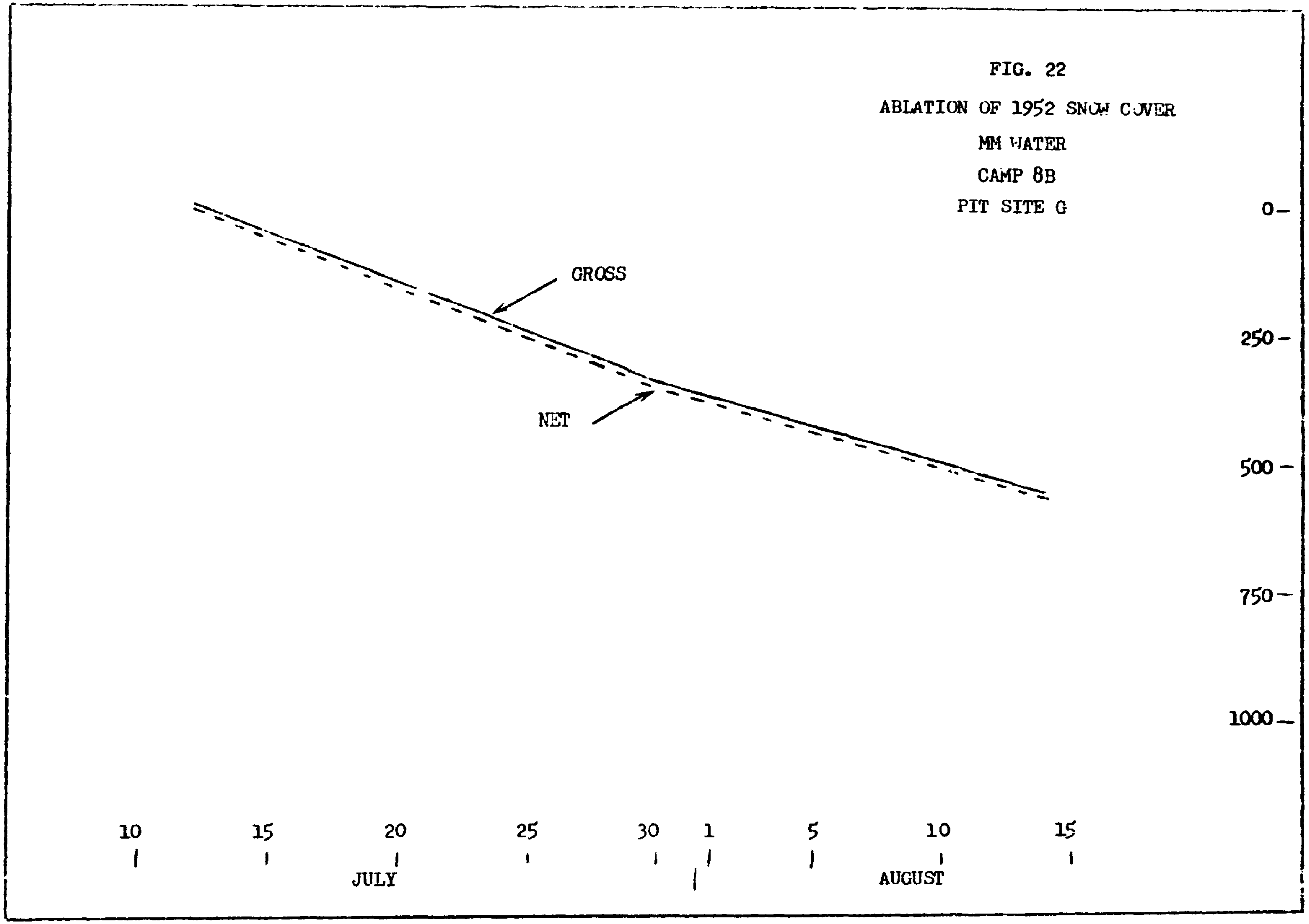


FIG. 22

ABLATION OF 1952 SNOW COVER

MM WATER

CAMP 8B

PIT SITE G

FIG. 23

ABLATION OF 1952 SNOW COVER
MM WATER
CAMP 9B
PIT SITE C

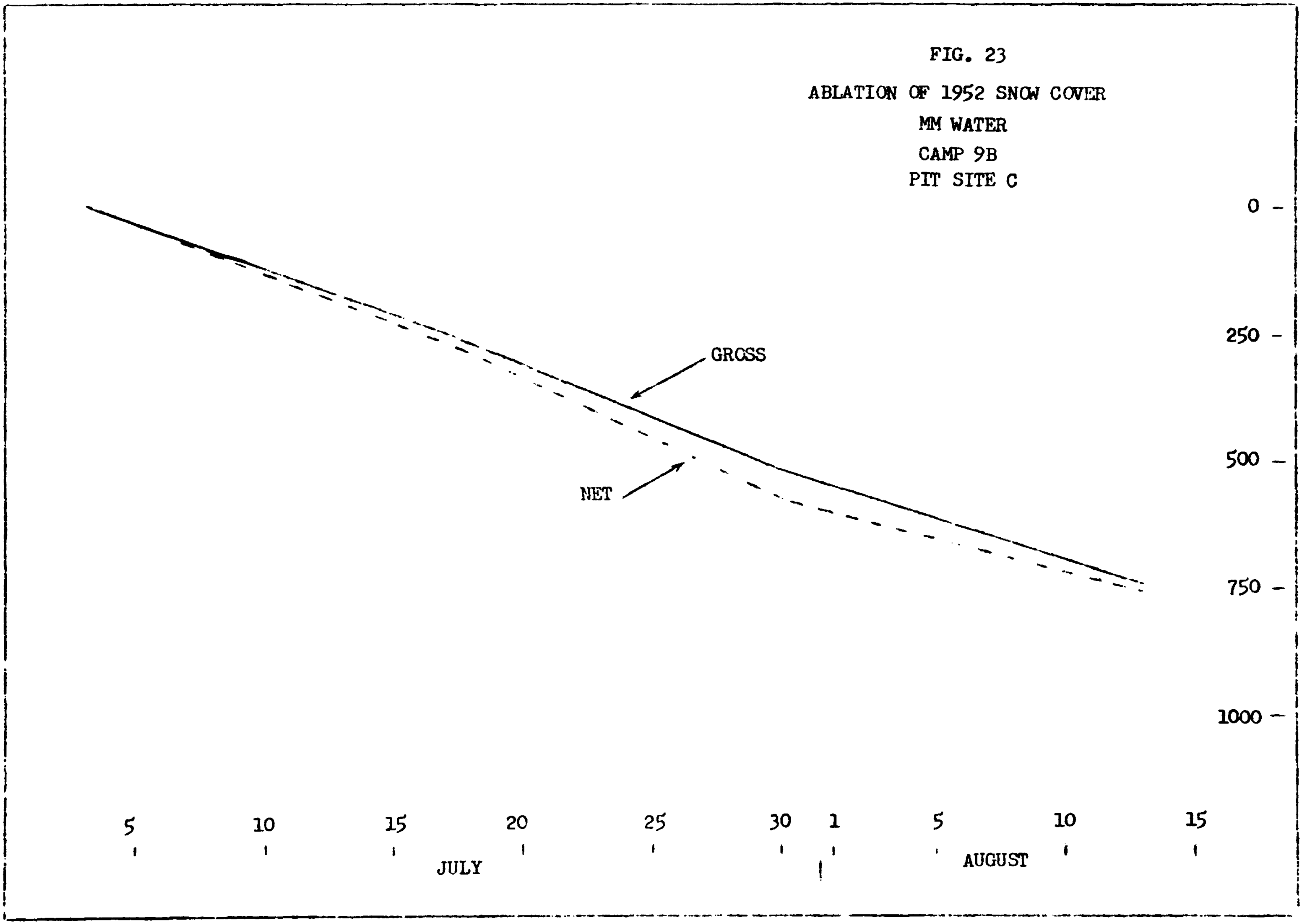


FIG. 24 Making observations on a pit wall. Cone hardness gauge is being used on a smoothed section of the wall; buckets are for collecting snow samples for pollen analysis.

FIG. 25—Use of the ram penetrometers. Operator is raising the ram weight of the standard penetrometer. On the left is the improvised penetrometer.

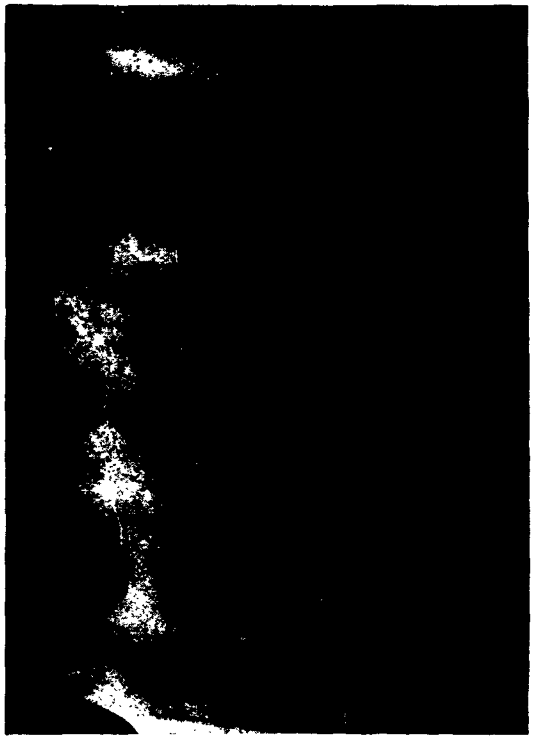
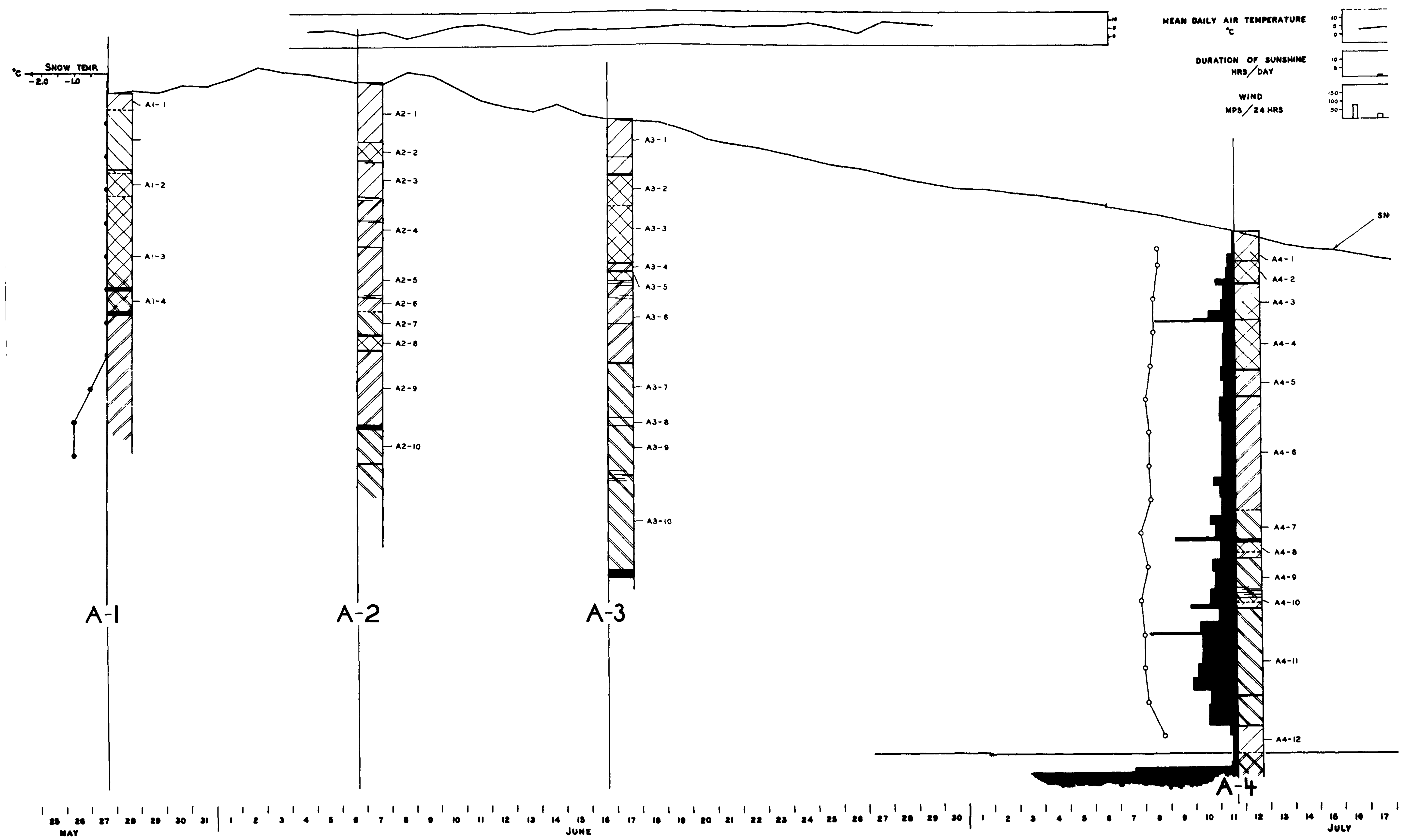
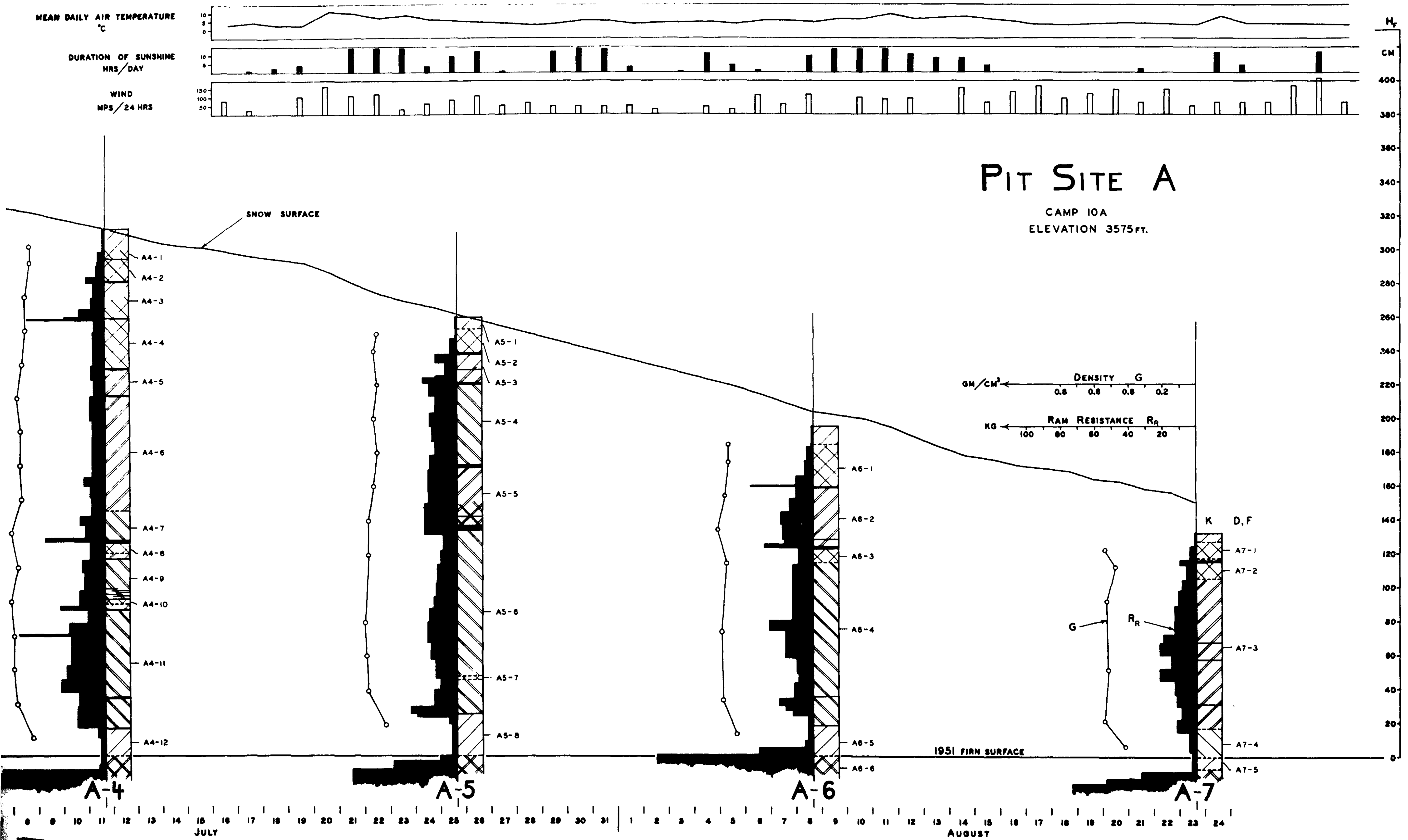


FIG. 26 Variations in snow hardness revealed by modeling with a brush. Note that the snow on the right which was not brushed appears homogeneous.

PROFILE I - Time profile for pit site A, Taku Glacier, showing density and ram resistance to left of axes; stratigraphy with a rough estimation of snow hardness (symbols follow usage of International Snow Classification) and location of levels at which photographs were taken are shown to right of axes. Meteorological record for portion of study period is displayed above. For further explanation see text page 17.



MEAN DAILY AIR TEMPERATURE °C
DURATION OF SUNSHINE HRS/DAY
WIND MPS/24 HRS
°C SNOW TEMP.
-2.0
-1.0
A1-1
A1-2
A1-3
A1-4
A2-1
A2-2
A2-3
A2-4
A2-5
A2-6
A2-7
A2-8
A2-9
A2-10
A3-1
A3-2
A3-3
A3-4
A3-5
A3-6
A3-7
A3-8
A3-9
A3-10
A4-1
A4-2
A4-3
A4-4
A4-5
A4-6
A4-7
A4-8
A4-9
A4-10
A4-11
A4-12
A-1
A-2
A-3
A-4
MAY
JUNE
JULY

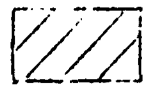
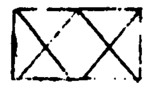

PIT SITE A
CAMP 10A
ELEVATION 3575 FT.
MEAN DAILY AIR TEMPERATURE °C
DURATION OF SUNSHINE HRS/DAY
WIND MPS/24 HRS
SNOW SURFACE
1951 FIRN SURFACE
DENSITY G
GM/CM³
RAM RESISTANCE R_R
KG
K
D, F
A-4
A-5
A-6
A-7
JULY
AUGUST
H_F
CM
2

PROFILE II - Time profile for pit site B, Taku Glacier, showing density and ram resistance to left of axes; stratigraphy with a rough estimation of snow hardness (symbols follow usage of International Snow Classification) and location of levels at which photographs were taken are shown to right of axes. For further explanation see text page 17.

GRAPHIC AND LETTER SYMBOLS USED IN PROFILES

I. Strength of the structure, K

K_s = shearing strength without normal stress

Term	Range of K_s	Handtest*	Graphic symbol
very low (very soft)	0 - 10 g/cm^2	fist	
low (soft)	10 - 75 "	4 fingers	
medium	75 - 250 "	1 finger	
high (hard)	250 - 750 "	Pencil	 or 
very high (very hard)	> 750 "	Knife	
compact (ice)	(up to 10000 ")		

*Handtest: The object indicated for a certain range can be pushed into the snow without considerable effort, but not the one mentioned in the foregoing range.

II. Other code letters

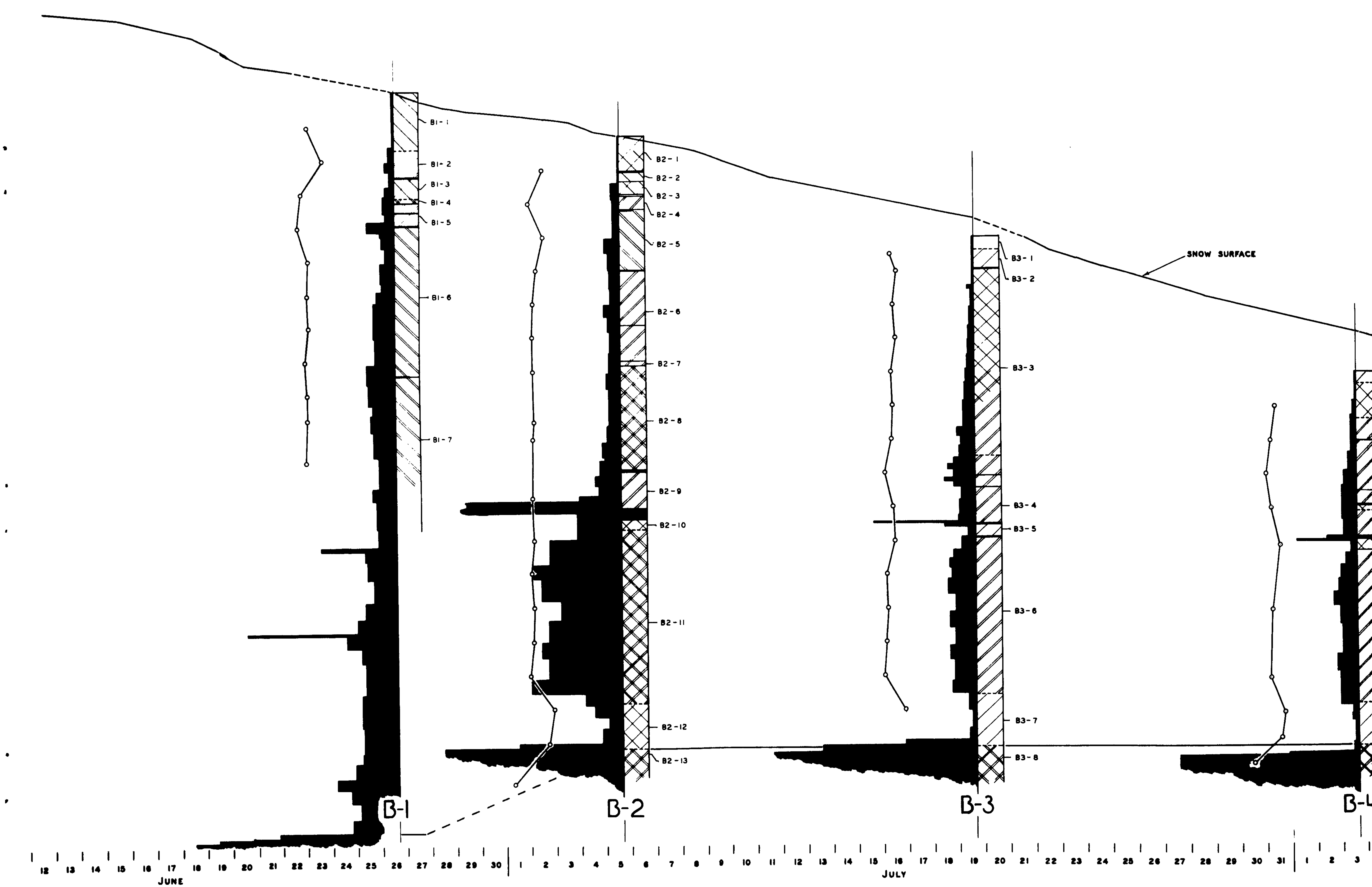
D Size of a particle

F Shape (form) of a particle (these properties were recorded photographically, see Plate I at end of this report)

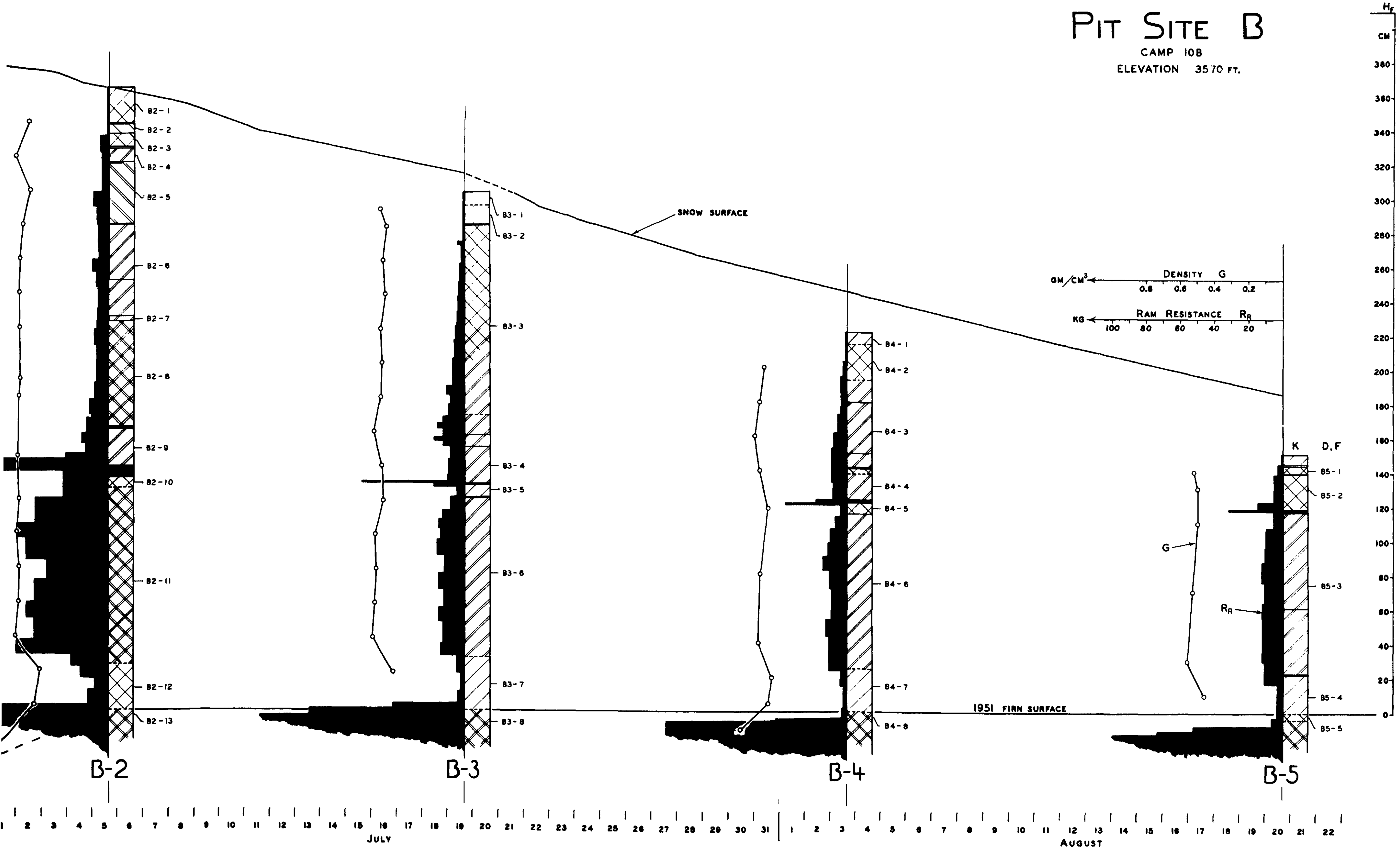
G Specific gravity, density

H Vertical coordinate from ground
(H_f = vertical coordinate from 1951 firn)

R Hardness, related to a particular instrument
(R_r = cone penetrometer)



SNOW SURFACE
B1-1
B1-2
B1-3
B1-4
B1-5
B1-6
B1-7
B2-1
B2-2
B2-3
B2-4
B2-5
B2-6
B2-7
B2-8
B2-9
B2-10
B2-11
B2-12
B2-13
B3-1
B3-2
B3-3
B3-4
B3-5
B3-6
B3-7
B3-8
B-1
B-2
B-3
B-4
12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
JUNE
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
JULY
1 2 3



PIT SITE B
CAMP 10B
ELEVATION 3570 FT.
SNOW SURFACE
1951 FIRN SURFACE
DENSITY G
GM/CM3
RAM RESISTANCE R_R
KG
G
R_R
K
D.F
H_F
CM
B-2
B-3
B-4
B-5
JULY
AUGUST

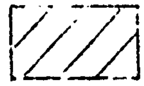
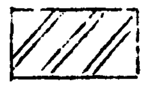
2

PROFILE III - Time profile for pit site C, Taku Glacier, showing density and ram resistance to left of axes; stratigraphy with a rough estimation of snow hardness (symbols follow usage of International Snow Classification) and location of levels at which photographs were taken are shown to right of axes. For further explanation see text page 17.

GRAPHIC AND LETTER SYMBOLS USED IN PROFILES

I. Strength of the structure, K

K_s = shearing strength without normal stress

Term	Range of K_s	Handtest*	Graphic symbol
very low (very soft)	0 - 10 g/cm^2	fist	
low (soft)	10 - 75 "	4 fingers	
medium	75 - 250 "	1 finger	
high (hard)	250 - 750 "	Pencil	 or 
very high (very hard)	$>$ 750 "	Knife	
compact (ice)	(up to 10000 ")		

*Handtest: The object indicated for a certain range can be pushed into the snow without considerable effort, but not the one mentioned in the foregoing range.

II. Other code letters

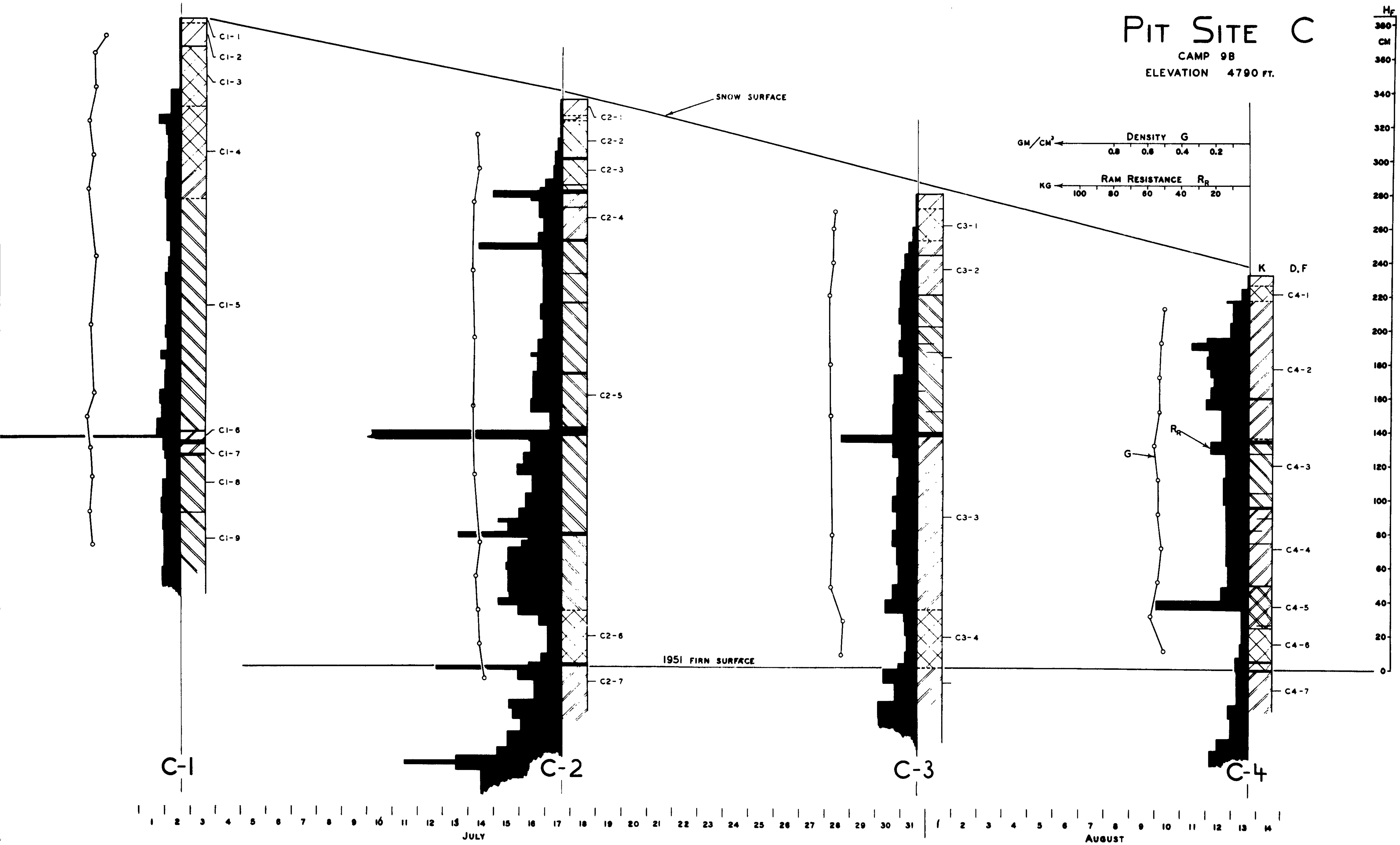
D Size of a particle

F Shape (form) of a particle (these properties were recorded photographically, see Plate I at end of this report)

G Specific gravity, density

H Vertical coordinate from ground
(H_f = vertical coordinate from 1951 firn)

R Hardness, related to a particular instrument
(R_r = cone penetrometer)



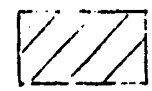
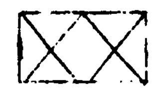
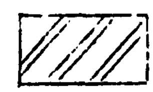
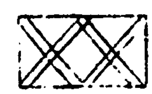
PIT SITE C
CAMP 9B
ELEVATION 4790 FT.
DENSITY G
GM/CM³
RAM RESISTANCE R_R
KG
H_F
CM
SNOW SURFACE
1951 FIRN SURFACE
K
D, F
R_R
G
C-1
C-2
C-3
C-4
JULY
AUGUST

PROFILE IV - Time profile for pit site G, Taku Glacier, showing density and ram resistance to left of axes; stratigraphy with a rough estimation of snow hardness (symbols follow usage of International Snow Classification) and location of levels at which photographs were taken are shown to right of axes. For further explanation see text page 17.

GRAPHIC AND LETTER SYMBOLS USED IN PROFILES

I. Strength of the structure, K

K_s = shearing strength without normal stress

Term	Range of K_s	Handtest*	Graphic symbol
very low (very soft)	0 - 10 g/cm^2	fist	
low (soft)	10 - 75 "	4 fingers	
medium	75 - 250 "	1 finger	
high (hard)	250 - 750 "	Pencil	 or 
very high (very hard)	> 750 "	Knife	
compact (ice)	(up to 10000 ")		

*Handtest: The object indicated for a certain range can be pushed into the snow without considerable effort, but not the one mentioned in the foregoing range.

II. Other code letters

D Size of a particle

F Shape (form) of a particle (these properties were recorded photographically, see Plate I at end of this report)

G Specific gravity, density

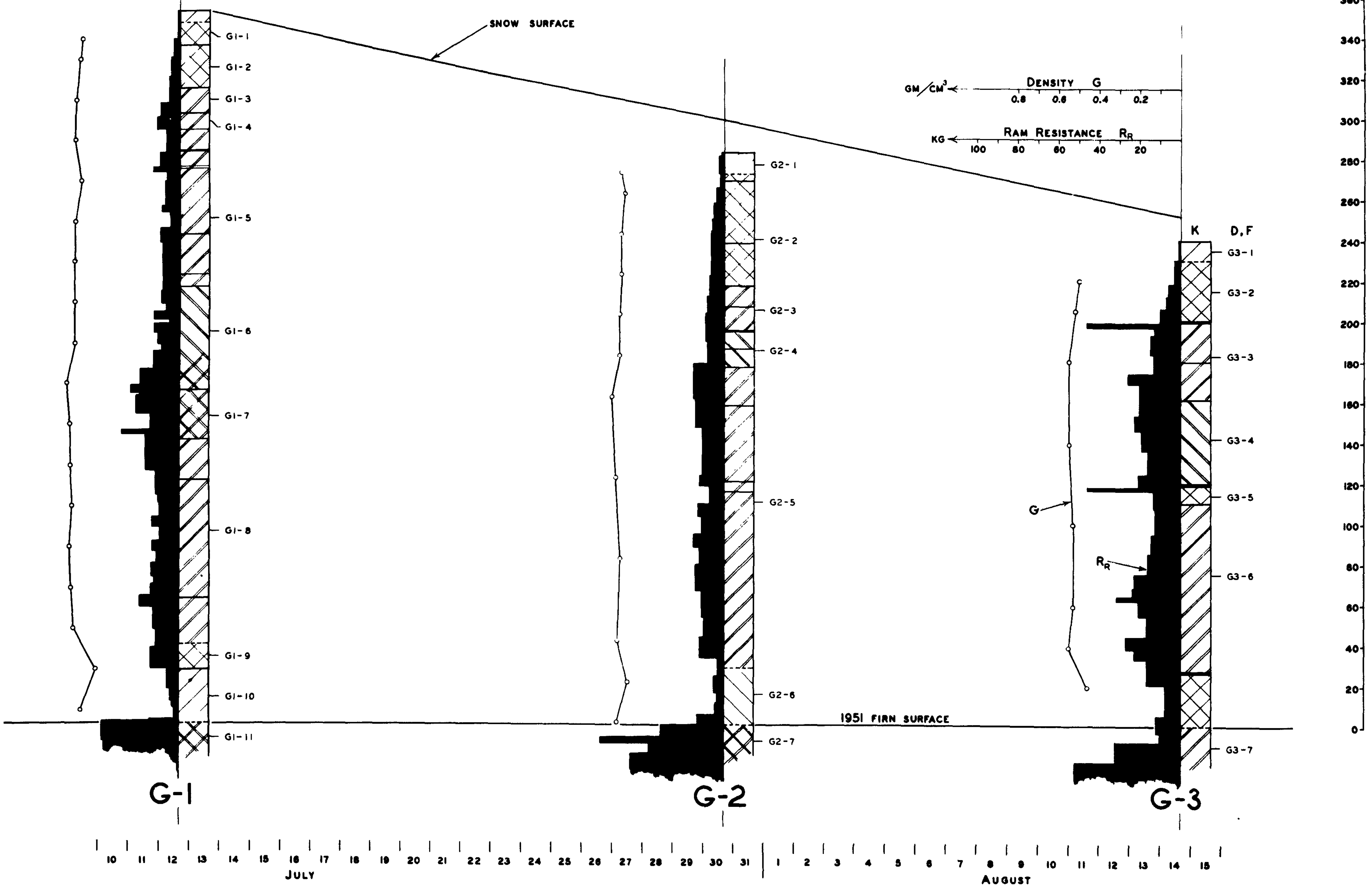
H Vertical coordinate from ground
(H_f = vertical coordinate from 1951 firn)

R Hardness, related to a particular instrument
(R_r = cone penetrometer)

Pit Site G

CAMP 8B

ELEVATION 4630 FT.

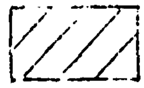


PROFILE V - Time profile for pit site H, Taku Glacier, showing density and ram resistance to left of axes; stratigraphy with a rough estimation of snow hardness (symbols follow usage of International Snow Classification) and location of levels at which photographs were taken are shown to right of axes. Note: density for pit H-1 has been erroneously plotted; 0.15 gm/cm^3 must be added to all the given density values in order to obtain correct ones. For further explanation see text page 17.

GRAPHIC AND LETTER SYMBOLS USED IN PROFILES

I. Strength of the structure, K

K_s = shearing strength without normal stress

Term	Range of K_s	Handtest*	Graphic symbol
very low (very soft)	0 - 10 g/cm^2	fist	
low (soft)	10 - 75 "	4 fingers	
medium	75 - 250 "	1 finger	
high (hard)	250 - 750 "	Pencil	 or 
very high (very hard)	> 750 "	Knife	
compact (ice)	(up to 10000 ")		

*Handtest: The object indicated for a certain range can be pushed into the snow without considerable effort, but not the one mentioned in the foregoing range.

II. Other code letters

D Size of a particle

F Shape (form) of a particle (these properties were recorded photographically, see Plate I at end of this report)

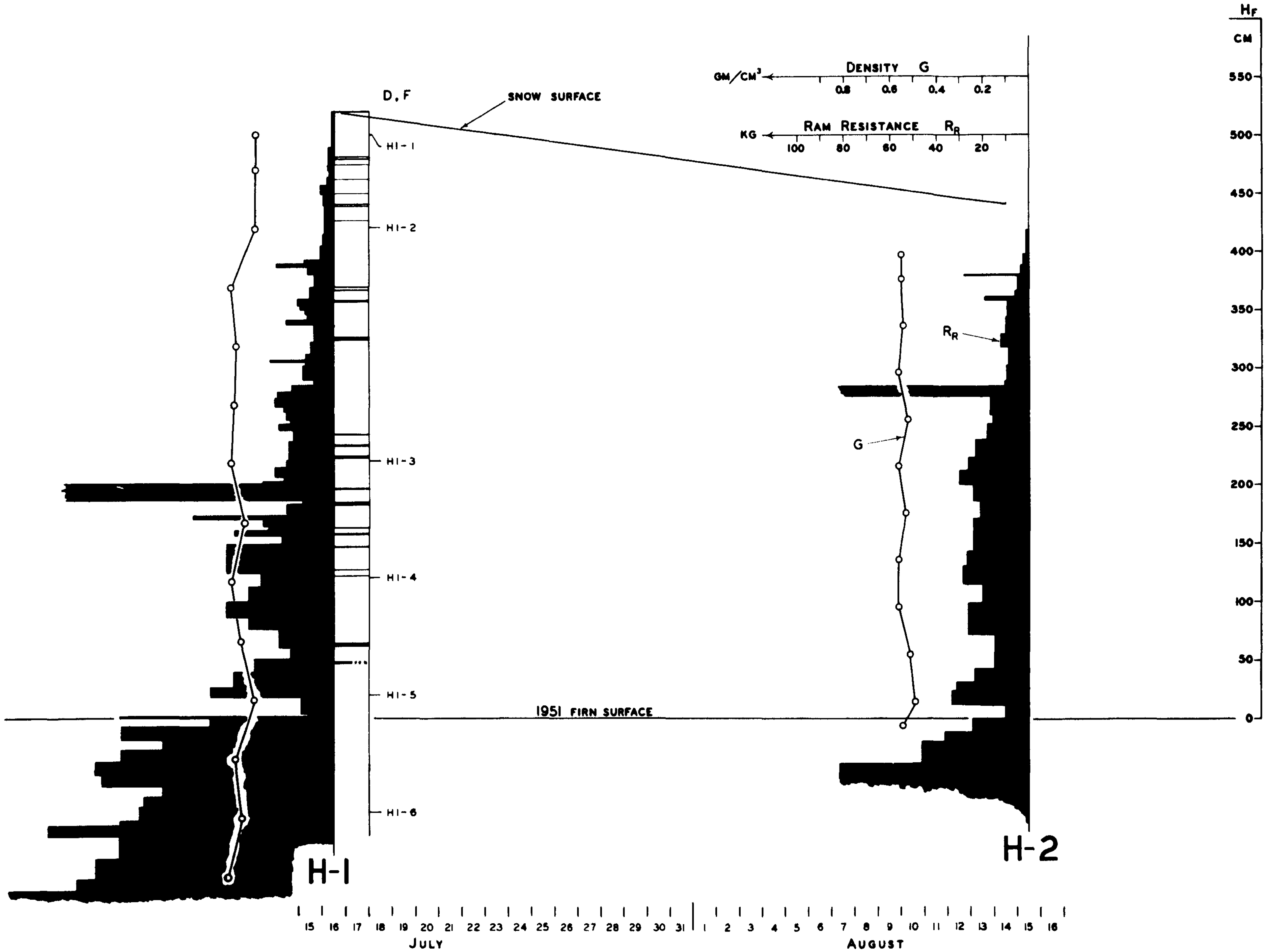
G Specific gravity, density

H Vertical coordinate from ground
(H_f = vertical coordinate from 1951 firn)

R Hardness, related to a particular instrument
(R_r = cone penetrometer)

Pit Site H

CAMP 8
ELEVATION 5915 FT.



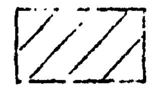
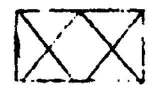
PROFILE VI - Snow variations along the surface of Taku Glacier in the second week of July, 1952, shown by profiles between Camp 10B and the transient snow line (between pit sites B-2 and D). Density and ram resistance to left of axes; stratigraphy with a rough estimation of snow hardness (symbols follow usage of International Snow Classification) and location of levels at which photographs were taken are shown to right of axes. Small dots in graphic sections indicate rounded isometric grains. (No photographic record of particle shape, F, and size D, for these sections.) Particle size indicated by letter according to the following table.

Term	Code	Scale
very fine	a	0 mm – 0.5
fine	b	0.5 – 1.0
medium	c	1.0 – 2.0
coarse	d	2.0 – 4.0
very coarse	e	4.0 –

GRAPHIC AND LETTER SYMBOLS USED IN PROFILES

I. Strength of the structure, K

K_s = shearing strength without normal stress

Term	Range of K_s	Handtest*	Graphic symbol
very low (very soft)	0 - 10 g/cm^2	fist	
low (soft)	10 - 75 "	4 fingers	
medium	75 - 250 "	1 finger	
high (hard)	250 - 750 "	Pencil	 or 
very high (very hard)	> 750 "	Knife	
compact (ice)	(up to 10000 ")		

*Handtest: The object indicated for a certain range can be pushed into the snow without considerable effort, but not the one mentioned in the foregoing range.

II. Other code letters

D Size of a particle

F Shape (form) of a particle (these properties were recorded photographically, see Plate I at end of this report)

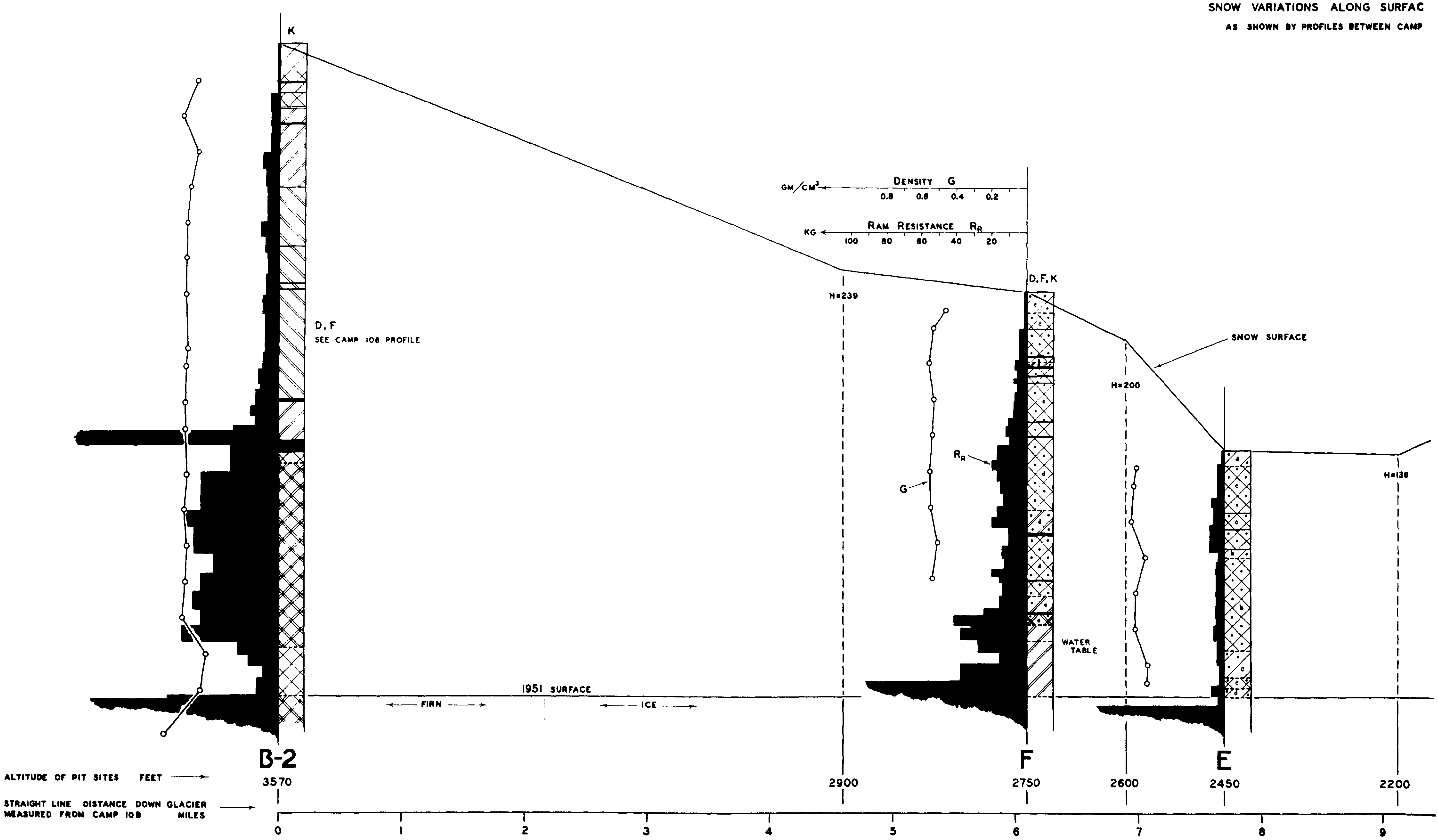
G Specific gravity, density

H Vertical coordinate from ground
(H_f = vertical coordinate from 1951 firn)

R Hardness, related to a particular instrument
(R_r = cone penetrometer)

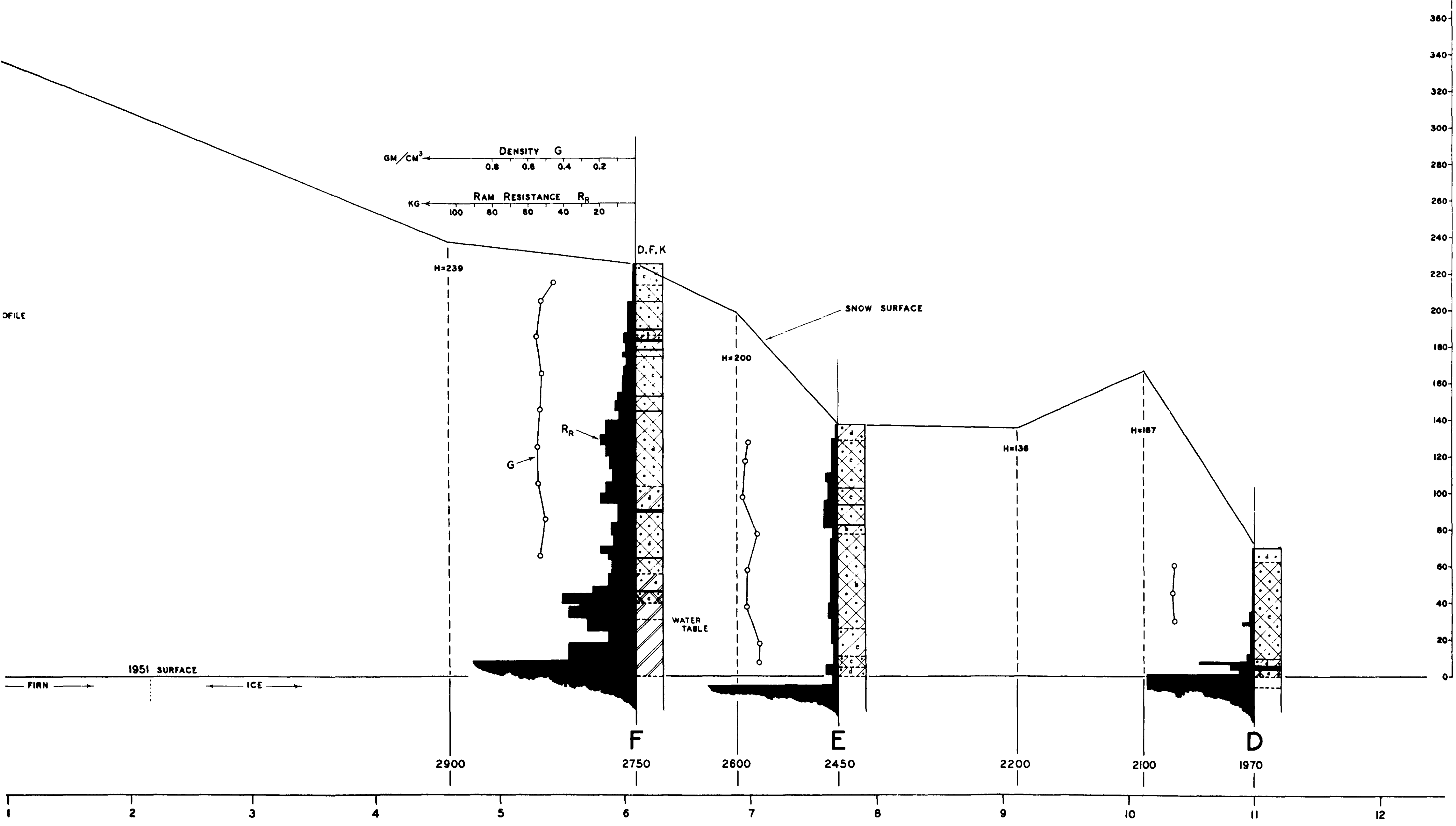
SNOW VARIATIONS ALONG SURFAC

AS SHOWN BY PROFILES BETWEEN CAMP



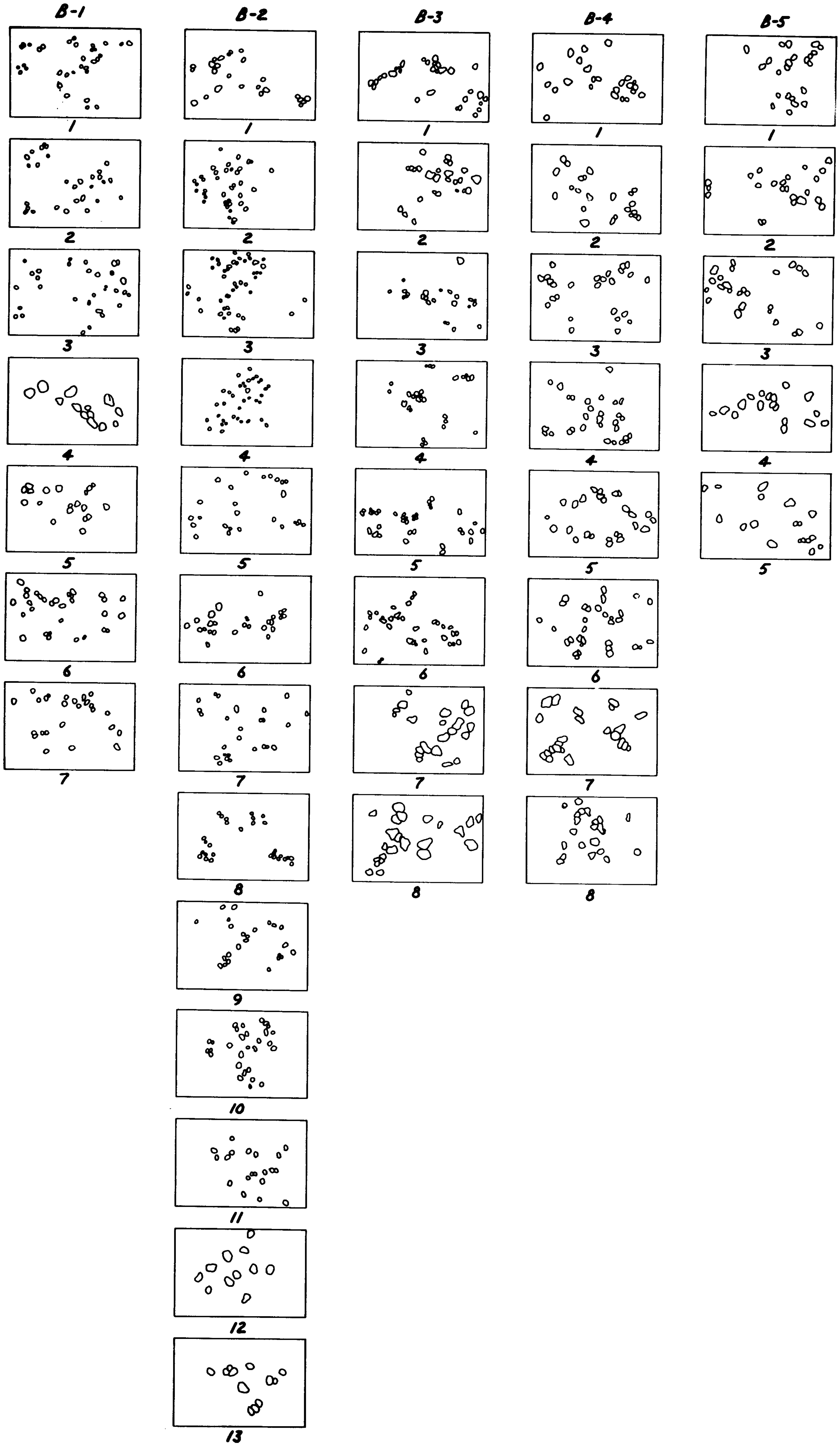
SNOW VARIATIONS ALONG SURFACE OF TAKU GLACIER

AS SHOWN BY PROFILES BETWEEN CAMP 10B AND TRANSIENT SNOW LINE



2

PLATE I - Snow crystals traced from photographs taken in pits at site B from levels indicated in Profile II. Magnification: x 2.


B-1
B-2
B-3
B-4
B-5
1
2
3
4
5
6
7
8
9
10
11
12
13